Improving Power Performance Measurements

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Wind Industry Forum

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Power Performance Measurements… Quick overview

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What?	**Compare Turbine Performance - Actual vs. Guaranteed**	
Why?	**Driven by project financiers**	
How?	**Traditionally….**	
Project Phase	**Pre-turbine Installation**	**Wind Farm Operation**
Flat Terrain	(No action required)	 Wind speed Power generation **Measure power performance**
Complex Terrain	Establish relationship between locations (Two masts required)  Mast location Turbine location **Site Calibration**	 Wind speed Power generation **Measure power performance**

Proven Power Performance

DNV·GL	Number of measurements	Number of measured turbines	Ratio EMAEP/ GAEP [%]
MM82	17	16	101.1% min / max results 97.7 – 106.8
MM92	33	31	100.0% min / max results 96.4 – 105.0
MM100	2	2	100.1% min / max results 100.0 – 100.2
3.0M122	1	1	100.1% min / max results n/a – n/a
3.2M114	2	2	101.1% min / max results 100.6 – 101.7
3.4M104	5	5	100.5% min / max results 98.2 – 103.1
3.4M114	1	1	100.1% min / max results n/a – n/a
3.6M114	1	1	100.5% min / max results n/a – n/a
5M	1	1	100.9% min / max results n/a – n/a
6.2M126	2	2	101.6% min / max results 101.2 – 102.0
6.2M152	1	1	101.7% min / max results n/a – n/a

Source: DNV GL, results as of January 2018

Power Performance Validation

- Conducted by independent measurement institutes
- Measurements reviewed by DNV GL
- Extensive data set of 66 measurement campaigns
- Comparison of Extrapolated Measured Annual Energy Production (EMAEP) and Guaranteed Annual Energy Production (GAEP)
- High power curve accuracy of 100.4% for the observed Senvion portfolio

Industry standard guarantees power performance of 100% minus measurement uncertainty

Aim & Agenda

Remember	**Not a legal requirement!** Choosing which test procedure to apply is purely a commercial (and technical) decision
Question	**What to consider so measurement fits project and financiers expectations?**
Agenda	PPM Drivers Recent changes to the industry standard (IEC 61400-12 series) Successful implementation

Power Performance Measurements

Drivers & Development

Power Performance Measurements
Drivers & Considerations

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Driven primarily by financiers

Stakeholders

Financial

- PPM negotiated during project financing
- Can incur payment of damages
- Pre-construction resource assessment assumptions

Markets

- Not a feature of all markets
- Common in Australia (large wind farms)
- Typical guarantee: 100% performance minus measurement uncertainty

Cost

- Measurement campaigns can be expensive
- Site calibration doubles mast requirements
- May not be economic for small (1-2 turbine) projects

Who's involved?

- Developers / Owners
- Turbine manufacturers (OEMs)
- Lenders / Financiers
- Mast / instrument suppliers
- Independent measurement bodies
- Landholders
- Department of Planning
- Project management / schedulers

Development of International Standard

IEC 61400-12 Power Performance Measurements

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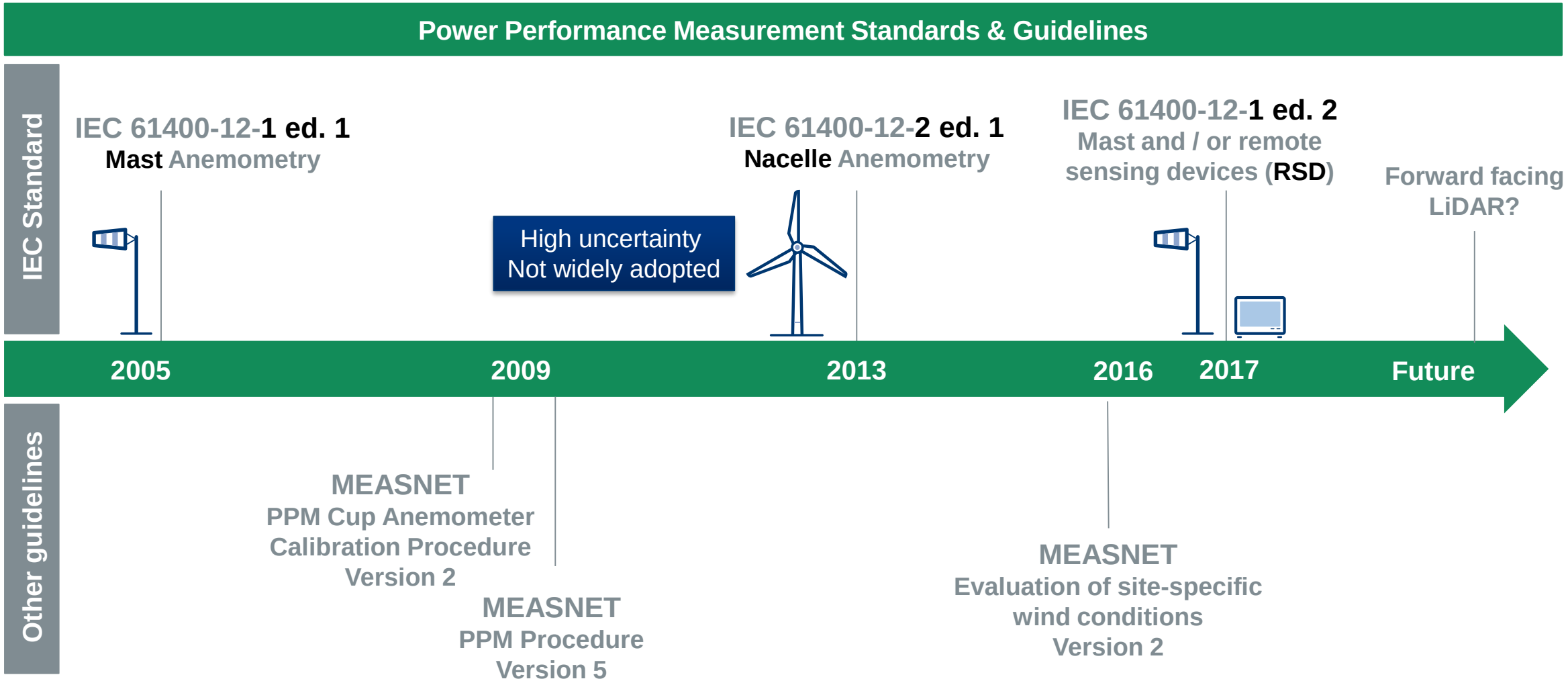

IEC 61400-12-1 ed. 2 (2017)

Changing landscape

IEC 61400-12-1 ed. 2 (2017)

What's changed?

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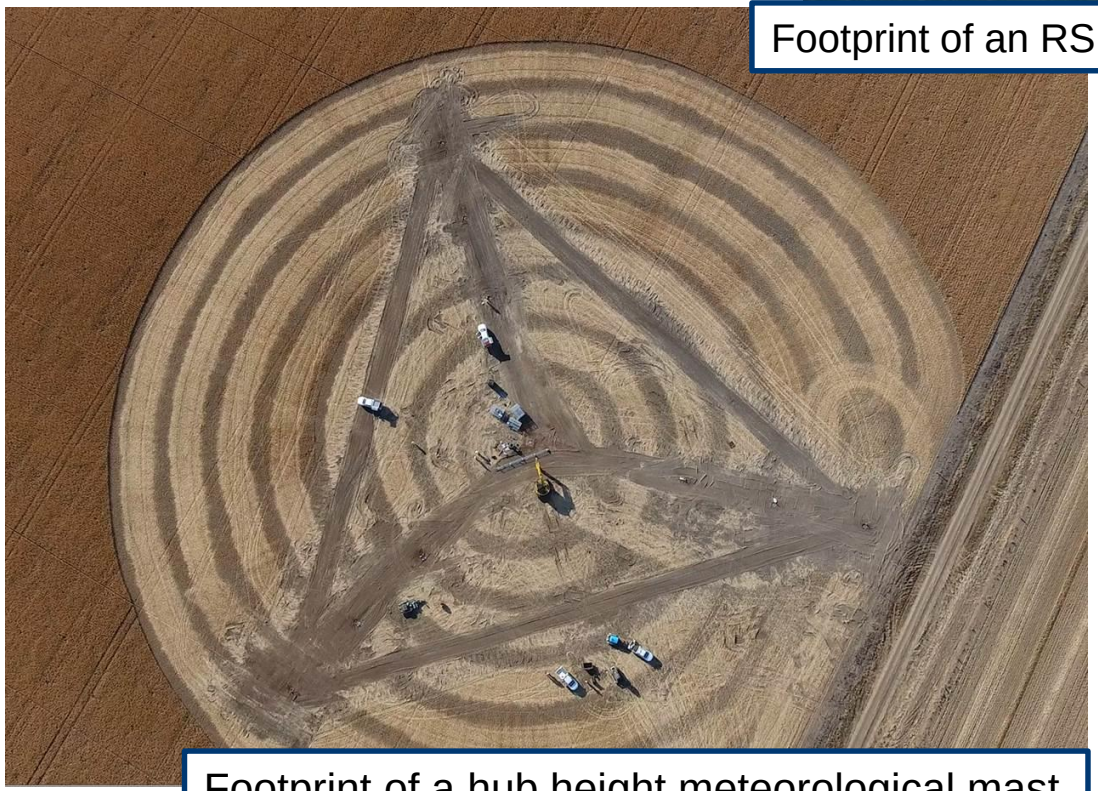
Remote Sensing Devices (RSDs) permitted (LiDAR and SoDAR)

Rotor Equivalent Wind Speed (REWS)

New criteria for site calibration

Uncertainty Annex updated

Footprint of an RSD e.g. LiDAR



Footprint of a hub height meteorological mast

What else is new? …. Quite a bit!

2017 version is three times longer than 2005.

New annex on mast induced flow distortion, revision to anemometer classifications, inclusion of ultrasonic anemometers, revision of air density correction, interpolation to bin centre method, cold climate annex added, database A changed to special database…

Measurement Configuration Options
Remote Sensing Devices (RSDs) – LiDAR & SoDAR

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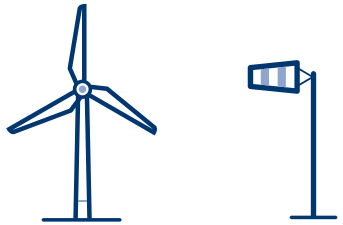
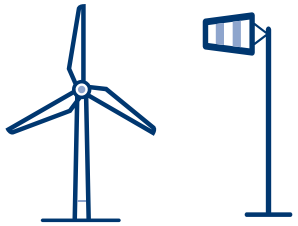
Any Terrain

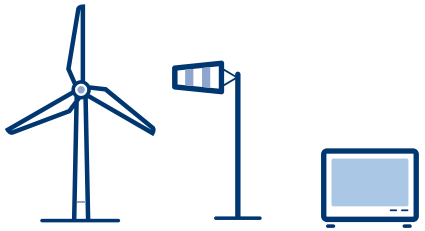


Hub height mast

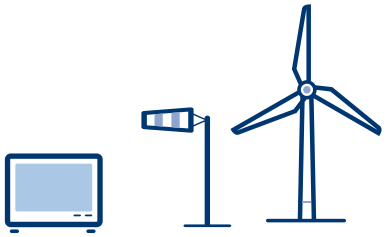


Tall mast
> Hub height

Flat Terrain Only



Hub height mast & RSD



Short mast* & RSD

*Min. 40 m or
Lower Tip Height

***does not remove need for hub height mast**

RSDs – LiDAR & SoDARs

Benefits

- Measure at multiple heights from ground level
- Cost compared to mast
- Mobility / re-use

Limitations

- Use in flat terrain only
- Hub height mast still required for RSD calibration (on / off-site)
- Cost benefit likely on flat sites with >1 PPM
- Pre- and post-calibration required (test timing)
- Single point of failure (lack of redundancy in measurement equipment)

Rotor Equivalent Wind Speed (REWS)

Variation across rotor (used instead of hub height wind speed)

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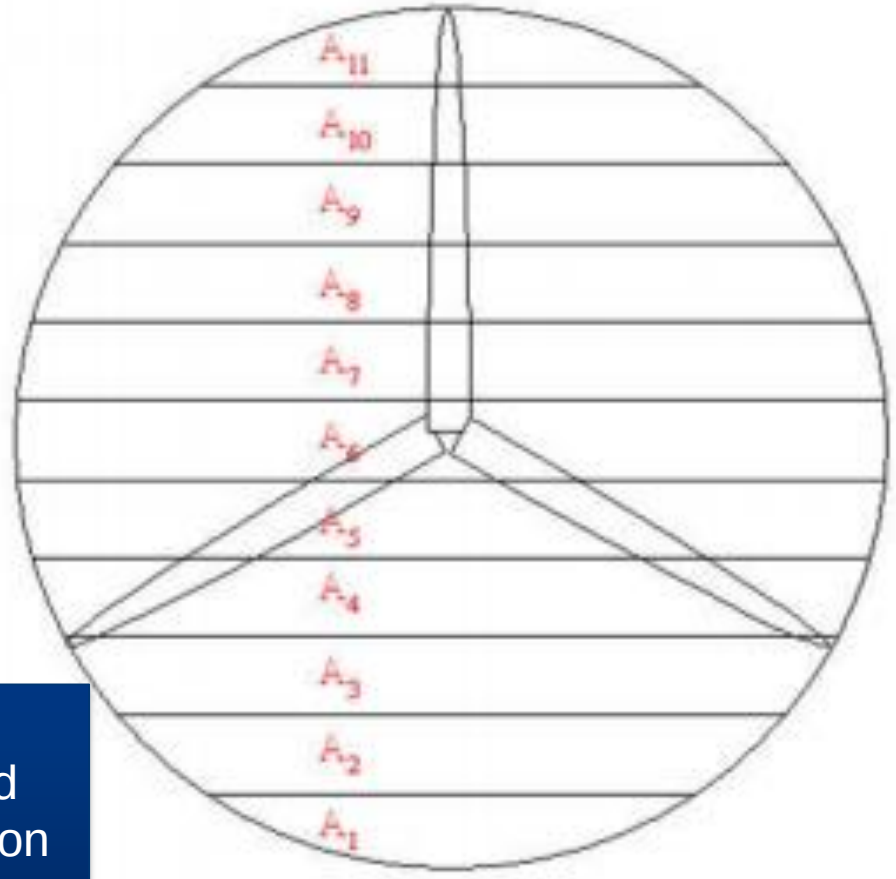

Considers wind speed and direction at multiple heights

$$REWS = \left(\sum_{i=1}^{n} \left(v_i \cos(\phi_i) \right)^3 \frac{A_i}{A} \right)^{\frac{1}{3}}$$

Rotor Equivalent Wind Speed (REWS)

Benefits

- Better captures wind conditions across rotor plane - particularly for larger turbines
- Allows for variation in wind speed (shear) and direction (veer)

Limitations

- Measurements >HH required (at least H + 2/3R)
- Additional equipment required
- Performance based on REWS must be compared to a power curve referenced to REWS (not hub height wind speed)

Terrain & Obstacle Assessment
Driving requirement for site calibration

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What's changed?

- **Area to be assessed** around the test turbine
- Impact is site dependent
- Site calibration is now / no longer required

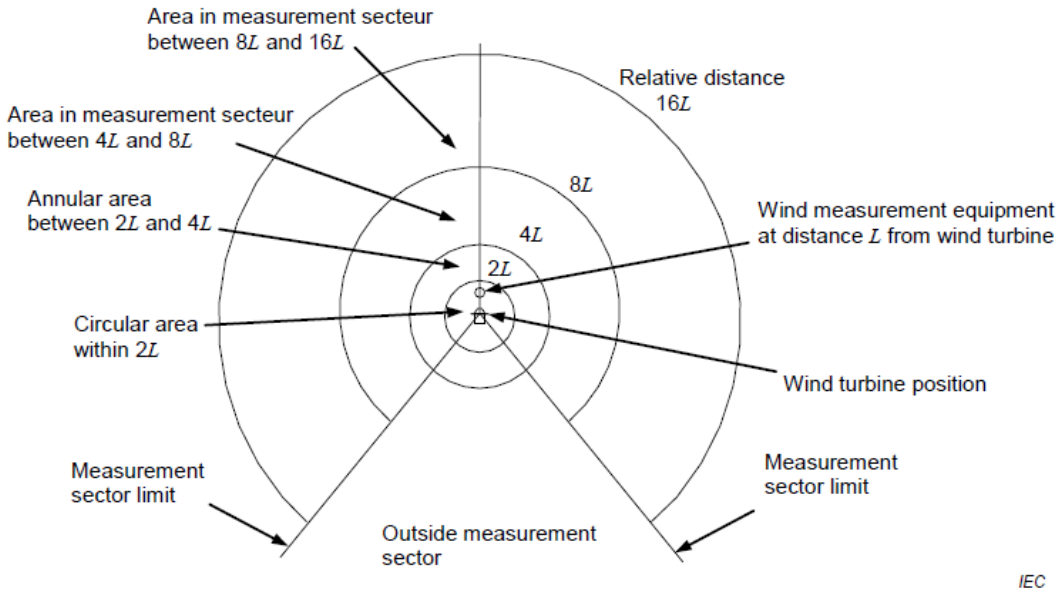

Figure B.1 – Illustration of area to be assessed, top view

'L' is the distance between the mast and test turbine (must be between 2-4 D, 2.5 is recommended)

Terrain Assessment

Drives requirement for site calibration

- Determines if a site is complex
- In complex sites, RSDs cannot be used & site calibration (two masts) required per test

Site Calibration

Impacts

- Required in complex terrain only (masts must be used)
- Masts required before turbine is installed (schedule)
- Doubles number of masts required (cost)

Uncertainty Assessment

Measurement Uncertainty

What is it?

- All measurements have a degree of uncertainty e.g. limitations of instrumentation (systematic error)
- Typical Power Performance Guarantee is 100% performance minus measurement uncertainty

What's changed?

- Uncertainty to allow for various instrumentation configurations and new assessments e.g. REWS
- Penalties apply if no correction for wind shear and wind veer is made

Impact?

- Not necessarily better / worse – project specific
- Much more involved process (time and effort by measurement bodies)

Implementation

Building on success

Implementing Successful PPM

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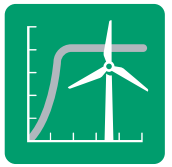

	Early Collaboration	Campaign Design	Implementation
Mast / Instrument Suppliers	■ Procurement	■ Measurement equipment	■ Installation and reporting
Independent Measurement Bodies	■ Power performance test plan	■ Siting masts	■ Regular progress updates
Owners / Developers / Financiers	■ Align on test procedure ■ Planning permission and associated environmental impact assessments	■ Configuration which meets financial objectives	■ Achieve contractual guarantees
Original Equipment Suppliers	■ Align on test procedure (filters, timing, retest) ■ Scheduling ■ Site specific power curve	■ Consideration of build schedule	■ Monitor progress ■ Achieve contractual guarantees

Take away

Drivers	Financiers expectations **PPM is a commercial decision**
Options are Available	IEC 2005 / 2013 / 2017 – Later not necessarily greater **Site-by-site decision which is most appropriate** (Measurement configuration, site calibration, cost, financiers expectations)
Successful Implementation	**Early collaboration** Alignment between stakeholders on test procedure and best way forward.

Thank you.

Catch us in the Operations & Maintenance session at 3:30 pm today
Katrina Swalwell will be presenting on LCOE Optimisation

Senvion is currently recruiting
Visit Senvion Careers page for more information

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