Improving Power Performance Measurements

Laura Browne, Plant Performance, Senvion
Wind Industry Forum
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# Power Performance Measurements… Quick overview

<table>
<thead>
<tr>
<th>What?</th>
<th>Compare Turbine Performance - Actual vs. Guaranteed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Why?</td>
<td>Driven by project financiers</td>
</tr>
<tr>
<td>How?</td>
<td>Traditionally….</td>
</tr>
</tbody>
</table>

## Project Phase

<table>
<thead>
<tr>
<th>Flat Terrain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-turbine Installation</td>
</tr>
<tr>
<td>(No action required)</td>
</tr>
</tbody>
</table>

## Complex Terrain

<table>
<thead>
<tr>
<th>Establish relationship between locations (Two masts required)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind speed</td>
</tr>
<tr>
<td>Power generation</td>
</tr>
<tr>
<td><strong>Measure power performance</strong></td>
</tr>
</tbody>
</table>

## Site Calibration

<table>
<thead>
<tr>
<th>Mast location</th>
<th>Turbine location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind speed</td>
<td>Power generation</td>
</tr>
<tr>
<td><strong>Measure power performance</strong></td>
<td></td>
</tr>
</tbody>
</table>
### Proven Power Performance

<table>
<thead>
<tr>
<th></th>
<th>Number of measurements</th>
<th>Number of measured turbines</th>
<th>Ratio EMAEP/GAEP [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MM82</strong></td>
<td>17</td>
<td>16</td>
<td>101.1%</td>
</tr>
<tr>
<td><strong>MM92</strong></td>
<td>33</td>
<td>31</td>
<td>100.0%</td>
</tr>
<tr>
<td><strong>MM100</strong></td>
<td>2</td>
<td>2</td>
<td>100.1%</td>
</tr>
<tr>
<td><strong>3.0M122</strong></td>
<td>1</td>
<td>1</td>
<td>100.1%</td>
</tr>
<tr>
<td><strong>3.2M114</strong></td>
<td>2</td>
<td>2</td>
<td>101.1%</td>
</tr>
<tr>
<td><strong>3.4M104</strong></td>
<td>5</td>
<td>5</td>
<td>100.5%</td>
</tr>
<tr>
<td><strong>3.4M114</strong></td>
<td>1</td>
<td>1</td>
<td>100.1%</td>
</tr>
<tr>
<td><strong>3.6M114</strong></td>
<td>1</td>
<td>1</td>
<td>100.5%</td>
</tr>
<tr>
<td><strong>5M</strong></td>
<td>1</td>
<td>1</td>
<td>100.9%</td>
</tr>
<tr>
<td><strong>6.2M126</strong></td>
<td>2</td>
<td>2</td>
<td>101.6%</td>
</tr>
<tr>
<td><strong>6.2M152</strong></td>
<td>1</td>
<td>1</td>
<td>101.7%</td>
</tr>
</tbody>
</table>

Source: DNV GL, results as of January 2018

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**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
<table>
<thead>
<tr>
<th><strong>Aim &amp; Agenda</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Remember</strong></td>
</tr>
<tr>
<td>Not a legal requirement!</td>
</tr>
<tr>
<td>Choosing which test procedure to apply is purely a commercial (and technical) decision</td>
</tr>
<tr>
<td><strong>Question</strong></td>
</tr>
<tr>
<td>What to consider so measurement fits project and financiers expectations?</td>
</tr>
<tr>
<td><strong>Agenda</strong></td>
</tr>
<tr>
<td>PPM Drivers</td>
</tr>
<tr>
<td>Recent changes to the industry standard (IEC 61400-12 series)</td>
</tr>
<tr>
<td>Successful implementation</td>
</tr>
</tbody>
</table>
Power Performance Measurements
Drivers & Development
## Power Performance Measurements
### Drivers & Considerations

### Driven primarily by financiers

<table>
<thead>
<tr>
<th>Financial</th>
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</thead>
<tbody>
<tr>
<td>PPM negotiated during project financing</td>
</tr>
<tr>
<td>Can incur payment of damages</td>
</tr>
<tr>
<td>Pre-construction resource assessment assumptions</td>
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</tbody>
</table>

### Markets

<table>
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<tr>
<th>Not a feature of all markets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common in Australia (large wind farms)</td>
</tr>
<tr>
<td>Typical guarantee: 100% performance minus measurement uncertainty</td>
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### Cost

<table>
<thead>
<tr>
<th>Measurement campaigns can be expensive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site calibration doubles mast requirements</td>
</tr>
<tr>
<td>May not be economic for small (1-2 turbine) projects</td>
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### Who’s involved?

<table>
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<tr>
<th>Developers / Owners</th>
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</thead>
<tbody>
<tr>
<td>Turbine manufacturers (OEMs)</td>
</tr>
<tr>
<td>Lenders / Financiers</td>
</tr>
<tr>
<td>Mast / instrument suppliers</td>
</tr>
<tr>
<td>Independent measurement bodies</td>
</tr>
<tr>
<td>Landholders</td>
</tr>
<tr>
<td>Department of Planning</td>
</tr>
<tr>
<td>Project management / schedulers</td>
</tr>
</tbody>
</table>
Development of International Standard
IEC 61400-12 Power Performance Measurements

Power Performance Measurement Standards & Guidelines

- IEC 61400-12-1 ed. 1
  Mast Anemometry
  2005

- IEC 61400-12-2 ed. 1
  Nacelle Anemometry
  2009

  High uncertainty
  Not widely adopted

- IEC 61400-12-1 ed. 2
  Mast and/or remote sensing devices (RSD)
  2013

- Forward facing LiDAR?
  2016

- Future

Other guidelines

- MEASNET PPM Cup Anemometer
  Calibration Procedure Version 2

- MEASNET PPM Procedure Version 5

- MEASNET Evaluation of site-specific wind conditions
  Version 2

2017
What's changed?

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

Rotor Equivalent Wind Speed (REWS)

New criteria for site calibration

Uncertainty Annex updated

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

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)

**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)

Considers wind speed and direction at multiple heights

\[
REWS = \left( \sum_{i=1}^{n} (v_i \cos(\phi_i))^3 \frac{A_i}{A} \right) \frac{1}{3}
\]
Terrain & Obstacle Assessment
Driving requirement for site calibration

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

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

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

**Impacts**

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

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

### Early Collaboration
- **Mast / Instrument Suppliers**
  - Procurement
  - Measurement equipment

- **Independent Measurement Bodies**
  - Power performance test plan
  - Siting masts

- **Owners / Developers / Financiers**
  - Align on test procedure
  - Planning permission and associated environmental impact assessments
  - Configuration which meets financial objectives

- **Original Equipment Suppliers**
  - Align on test procedure (filters, timing, retest)
  - Scheduling
  - Site specific power curve

### Campaign Design

- **Mast / Instrument Suppliers**
  - Procurement
  - Measurement equipment

- **Independent Measurement Bodies**
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### Implementation
- **Mast / Instrument Suppliers**
  - Procurement
  - Measurement equipment

- **Independent Measurement Bodies**
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- **Original Equipment Suppliers**
  - Align on test procedure (filters, timing, retest)
  - Scheduling
  - Site specific power curve
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

Senvion
Laura Browne
Plant Performance