Multiple 3-d Scanning Doppler Lidar and Wind Energy Resource Assessment

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Multiple 3-d Scanning Doppler Lidar and Wind Energy Resource Assessment

• Scanning Doppler Lidar Overview
• Scanning Lidar for WERA
• Dual-Doppler Lidar for WERA
• Value proposition of 1 year lidar deployment integrated into WERA and P-Values
Scanning Lidar: Principles of Operation

Doppler Lidar Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitter</td>
<td>Nd-Yag laser</td>
</tr>
<tr>
<td>Operating Wavelength</td>
<td>1.6/2µm</td>
</tr>
<tr>
<td>Energy per pulse</td>
<td>2mJ</td>
</tr>
<tr>
<td>Pulse repetition frequency</td>
<td>500 Hz</td>
</tr>
<tr>
<td>Data Rate</td>
<td>5 Hz</td>
</tr>
<tr>
<td>Range resolution</td>
<td>~50 - 100 m</td>
</tr>
<tr>
<td>Min range</td>
<td>436 m</td>
</tr>
<tr>
<td>Max range</td>
<td>10/15 km</td>
</tr>
</tbody>
</table>

$v_r(R, \phi, \theta) = U \sin \phi \cos \theta + V \cos \phi \cos \theta + W \sin \theta$

$V_r =$ Radial Velocity, $\phi =$ Azimuth Angle, $\theta =$ Elevation angle
$U, V, W =$ Components of wind speed

“LASER”
94% Correlation of wind speed
Distance between tower and lidar – 3.2 km

Krishnamurthy et al. 2012
1. Why does lidar retrieval accuracy reduce in the off-mean wind direction?

Radial velocity ~ 0 – No new information is provided!

2. What is the retrieval accuracy in the off-mean wind direction?

Conditional analysis with tower measurements shows correlation of 90% in wind speed.

\[v_r(R, \phi, \theta) = U \sin \phi \cos \theta + V \cos \phi \cos \theta + W \sin \theta\]

\[V_r = \text{Radial Velocity}, \quad \theta = \text{Elevation angle}, \quad \phi = \text{Azimuth Angle}\]

\[U, V, W = \text{Components of wind speed}\]
Dual-Doppler for Wind Energy Resource Assessment

- Intersecting lidar beams for 3-d wind vector
- Sample – 250 MW Wind Farm
- No. of Turbines – 125
- Rotor Diameter (RD) – 80m

- Spacing –
  Prevailing mean wind direction – 13 RD
  Off - mean wind direction – 3.5 RD
  Wind Farm Coverage – 14 km x 3 km

- Hub-height winds for 90% of the wind farm – ~42 sq km

- Winds speed spatial accuracy – ~100 m
Dual-Doppler Lidar

• Why?
  – Higher confidence in velocity retrievals
  – Reduces directional dependence
  – Measured hub-height winds at nearly all turbine locations
  – Turbulence parameters ($u_*, \sigma_u, \sigma_v, \sigma_w, u'w', v'w'$ etc.)
  – Input to mesoscale models – data assimilation
  – Can track atmospheric events – harmful to turbines

• Challenges
  – Synchronizing lidar beams from two instruments
  – Pointing accuracy and complex terrain blockage/placement

Newsom et al. 2005, Calhoun et al. 2006, Krishnamurthy et al. 2010
Value Proposition of Dual-Doppler Lidar in Wind Energy Resource Assessment

90% wind farm area dual-Doppler coverage at hub height

- Cost of dual 3-d Doppler lidar deployment for 1 year: ~$1.5 M
- ROI for a 250MW Wind Farm with 60-m towers?

<table>
<thead>
<tr>
<th>Uncertainty</th>
<th>60-m Towers</th>
<th>dual 3-d Doppler</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear</td>
<td>2%</td>
<td>0.25%</td>
</tr>
<tr>
<td>Micro-siting</td>
<td>6%</td>
<td>2%</td>
</tr>
</tbody>
</table>

a Lower range of uncertainty estimates
Other uncertainties in P-value calculation remain the same

<table>
<thead>
<tr>
<th></th>
<th>95% Confidence limits</th>
<th>P95/P50 ratio</th>
<th>P95 Production (Δ)</th>
<th>20 Year NPV (@$60/ MWh)</th>
<th>ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Year</td>
<td>Drops ~250 basis points</td>
<td>Δ 0.781 to 0.801</td>
<td>17,500 MWh</td>
<td>~ 9.4 M</td>
<td>~650%</td>
</tr>
<tr>
<td>20 Year</td>
<td>Drops ~400 basis points</td>
<td>Δ 0.852 to 0.883</td>
<td>27,500 MWh</td>
<td>~ 14.8 M</td>
<td>~1000%</td>
</tr>
</tbody>
</table>

Depends on your wind farm’s financing terms
Dual-Doppler to Track & Quantify Harmful Atmospheric Events

- Coplanar scans along 80 degree azimuth
- Height difference between Lidars
- Validation - Pointing accuracy

Hill et al. 2009
Dual-Doppler to Track & Quantify Harmful Atmospheric Events

Lidar can quantify:

a. Vorticity
b. Sub-rotors
c. Dissipation rate

Colors – Vorticity (s\(^{-1}\)); Contour – Swirl Strength; Arrows – Wind Direction

Turbine not to scale
Scanning Lidar’s Tool or Toy?

• Scientific advantage over towers for WERA? ✓
  – Large spatial extent coverage – reduces micro-siting uncertainty
  – Dual-Doppler – Higher retrieval accuracy
  – Dual-Doppler – reduces directional challenges

• Financially viable or good ROI? ✓
  – Uncertainty reduction by ~ 4% in WERA
  – 5x or 10x ROI for a 250MW wind farm

• Year long dual-Doppler lidar deployment is promising both financially and scientifically amidst PTC uncertainty!
References


Krishnamurthy, R et al., 2012: Coherent Doppler lidar for wind farm characterization. Wind Energy, doi: 10.1002/we.539


Boccippio, D 1995: A diagnostic analysis of the VVP single-Doppler retrieval technique, J. Atmos. Ocean Tech

Additional Slides
Dual-Doppler Lidar

Cautions:

- Height difference between Lidar’s should be taken into account
- Pointing accuracy