Utilizing Radar Measured Velocity Fields to Forecast Turbine Wind Speeds

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Introduction and Motivation

Wind energy today....

- Multi-billion dollar industry with over 60+ MW (through 2014) deployed.

Ultimate goal of decreasing the cost of energy and mitigating risk.
Conventional wind turbine feedback controllers are entirely reactive rather than proactive.

- Transients such as gusts, varying shears, and directional changes in the inflow all represent UNKNOWN disturbances.

Recent developments in remote sensing have led to much interest in the possibility of improving wind turbine controllers by providing preview information of the approaching wind field.

- Nacelle-mounted Look-Ahead Systems
  - Benefits....
  - Limitations...
Aim of Research

Although information of the near-upstream flow conditions has been examined through the use of nacelle mounted LIDAR systems, employing three dimensional wind field maps derived from scanning instruments to provide an extended wind speed forecast for individual turbine locations has never been investigated.
Texas Tech University maintains two research-grade mobile Ka-band Doppler radar systems.

- A single radar system is limited to deriving the radial component.
- A dual-Doppler scanning strategy allows for the extraction of the full horizontal velocity vector and construction of horizontal wind field maps.

### Radar Specifics

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Half-Power Beamwidth</td>
<td>0.49°</td>
</tr>
<tr>
<td>Along-Beam Range Resolution</td>
<td>15m</td>
</tr>
<tr>
<td>Revisit Time</td>
<td>~45 sec</td>
</tr>
</tbody>
</table>
Dual-Doppler Horizontal Wind Speed Synthesis (~45 sec Revisit Time)
In order to provide preview measurements of the upstream flow, the following steps must be taken:

1. Derive an upstream projection representative of the inflow.
   - Look angle of the upstream projection (Rotor Sweep Area Average of WD located 1D Upstream).
   - Spatial dimensions of the upstream projection (Point Measurement Along Path).

2. Forecast wind speeds measured upstream to the location of turbine.
   - Analyze wind speeds at hub height within upstream projection at distances between 1-6 D upstream at intervals of ~10 m.
   - Assuming the wind speed magnitude of the features remains constant with time, derive time offset for future feature arrival.

3. Generate a future-forecasted time series.
ABL Streaks and Advection of Momentum

Organized coherent structures are embedded within the turbulent flow fields of the ABL.

- Near-surface streaks, defined as elongated areas of enhanced/reduced wind speeds (Traumner et al. 2015).
- Shown using full-scale radar measurements to be skewed left of the wind direction (Lorsolo et al. 2008; Marathe 2014).

<table>
<thead>
<tr>
<th>Variation in Advection Between Actual and Projected Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
</tr>
<tr>
<td>Feature 1 🌟</td>
</tr>
<tr>
<td>Feature 2 🌟</td>
</tr>
</tbody>
</table>
Variation in Upstream Projection Paths

Propagation of upstream conditions based upon the governing wind direction is not sufficient to provide an extended preview of the approaching wind field.

- Variation between wind direction and actual momentum advection leads to inaccuracies in the future-forecasted time series.
Adapted Methods

Adjust Upstream Path to Account for Momentum Advection

- Upstream projection offset counterclockwise of the governing wind direction by four degrees.

<table>
<thead>
<tr>
<th>CC Degree Offset</th>
<th>RMSE Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3-sec Avg.</td>
</tr>
<tr>
<td>0</td>
<td>0.7471</td>
</tr>
<tr>
<td>1</td>
<td>0.7210</td>
</tr>
<tr>
<td>2</td>
<td>0.6978</td>
</tr>
<tr>
<td>3</td>
<td>0.6803</td>
</tr>
<tr>
<td><strong>4</strong></td>
<td><strong>0.6740</strong></td>
</tr>
<tr>
<td>5</td>
<td>0.6768</td>
</tr>
<tr>
<td>6</td>
<td>0.6849</td>
</tr>
</tbody>
</table>

0.073 ms\(^{-1}\) & 0.076 ms\(^{-1}\) reduction in RMSE for 3 and 5 second averages respectively.
Radar Derived Forecasted Wind Speeds

Dual-Doppler Horizontal Wind Speed

Forecasted Wind Speeds

RMS=0.06192

10-sec AVG

Nacelle 3-Cup
Radar Derived WS

Time (sec) After Scan Completion

X-distance
Y-distance

80m
Radar Derived Forecasted Wind Speeds

Radar Measured Forecasted Wind Turbine Wind Speeds
27 OCT 2011--12:37:55-12:40:57 UTC

5-sec Average

Wind Speed, m/s

RMSE=0.29384

Nacelle 3-Cup
Radar Derived WS

Time, sec

20 40 60 80 100 120 140 160 180

10-sec Average

Wind Speed, m/s

RMSE=0.17426

Nacelle 3-Cup
Radar Derived WS

Time, sec

20 40 60 80 100 120 140 160 180
Forecasts Across Observational Period
(52 min 12 sec)

<table>
<thead>
<tr>
<th>Averaging Time</th>
<th>RMSE Value (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-sec</td>
<td>0.71</td>
</tr>
<tr>
<td>3-sec</td>
<td>0.67</td>
</tr>
<tr>
<td>5-sec</td>
<td>0.65</td>
</tr>
<tr>
<td>10-sec</td>
<td>0.59</td>
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Concluding Remarks

Preliminary results demonstrate the ability to predict future conditions at the turbine leveraging radar-derived dual-Doppler horizontal wind field maps.

- Scanning instruments allow for the ability to accurately forecast wind speeds 45+ seconds or more in advance from the turbine.
  - Elevating the instruments to hub height could reduce time required to collect hub height information by an order of magnitude further enhancing this method.

- Coordinated deployment of multiple specialized Doppler radar systems can provide the foundational information to construct proactively responding turbine control systems.
Next Steps... Plant Scale

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References


