Operating wind farm monitoring and performance optimization

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Wind farm performance map

% of average turbine production

80% 72%
Why analyze your operating wind farm?

- Understand individual turbine performance and identify frequent faults
- Quantify discrepancies between actual and forecast energy production
- Minimize uncertainty in the long-term forecast
- Maximize wind farm value

1% production loss on a 100MW wind farm results in $250k revenue loss
Actual versus forecast production

Main causes of the energy production discrepancies:

1) Windiness of operational period
2) Power performance
3) Availability
4) Uncertainty associated with the long-term forecast

Effects of **turbine performance** and **availability** on production are controllable by analyzing operating wind farm data.
Operational wind farm analyses – our experience

- GH has carried out performance analysis / monitoring of over 10GW of wind farms
  - Close to 15% of worldwide installed capacity

- In many cases corrective actions were successfully implemented following a GH performance assessment resulting in enhanced revenue

- Work to date has involved internationally widespread wind farms with operational periods from 6 months up to 15 years

- Over 1,000 wind farm years (or 25,000 turbine years) of operating wind farm production data studied to date
Operational wind farm analysis by country

Number of wind farms per country:

- Spain, 124
- US, 42
- Italy, 35
- Germany, 25
- France, 7
- Greece, 1
- Ireland, 9
- New Zealand, 1
- England, 15
- North Ireland, 3
- Portugal, 3
- Scotland, 9
- Wales, 12
- Sweden, 4
- Canada, 6
- Japan, 8
- India, 3
- Sweden, 4

- US, 42
Operational wind farm analysis by turbine manufacturer

Number of turbines per manufacturer:
- Vestas, 2092
- Gamesa, 1842
- Ingecon, 546
- GE, 687
- Made, 991
- MHI, 473
- Zond, 440
- Bonus, 473
- DESA, 334
- DeWind, 53
- EHN, 52
- Enercon, 404
- Enron, 523
- Fuhrlander, 2
- Sudwind, 3
- Repower, 6
- Nordic, 1
- Nordex, 131
- NEG, 969
- WEG, 22
Detailed analysis of operating wind farm data
Use SCADA data to:

• Graphically represent a wind farm’s operation in time lapse animation
• Identify changes in power performance
• Assess availability
• Quantify energy losses / gains
• Estimate long-term energy
Identify changes in power performance

Detailed Forensic analysis of SCADA data techniques are needed

Examples:
- Pitch control malfunction
- Blade damage / fouling
- Control program problem
- Blade angle resetting (stall regulated turbines)
- Aerodynamic enhancements
- Constrained operation
Example of poor power performance

Pitch control malfunction
Additional example of poor power performance

- Wind speed
- Pitch setting adjustment
Final example of poor power performance

Wind speed

Power

Constrained operation
Power curve tracking tools

- Graph showing power output vs. wind speed for different months.
- Table with turbine ID, NACP Analysis, and comment indicating a 20% increase in Nov 02.
- Data for NVS and Energy across months.
Assess Availability

- Run-Time Availability (RTA) calculated based on SCADA data
  - The amount of time that the turbines were fully available to “run” as a fraction of the total time
- Establish if down-time correlated with high wind speed (e.g. utility enforced down-time or high wind faults)
- Establish if down-time correlated with loss of communications of the SCADA system
- Validate the manufacturer’s reported availability figures
- Assess Liquidated Damages or availability bonuses
Availability check using power and wind speed only

- Available
- Not available

Wind speed vs. Power
Reconciling actual production to budgeted production
Identify periods of poor power performance

- Constrained
- Normal
- Not available

Wind speed

Power

GARRAD HASSAN
How much energy has been lost?
Reconciling wind farm production

<table>
<thead>
<tr>
<th>Losses</th>
<th>Gains</th>
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</thead>
<tbody>
<tr>
<td>Wind speed lower than long-term</td>
<td>10</td>
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<tr>
<td>Availability lower than forecast</td>
<td>8</td>
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<tr>
<td>Power performance issues quantified</td>
<td>13</td>
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<tr>
<td>Forecast error</td>
<td>6</td>
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Potential for 6% increase in production or $1.5m in revenue annually
Reconciling wind farm production

Don’t leave detailed performance analysis until a lower than budget year!
Conclusions

- Regular monitoring of operating wind farm data can identify unnecessary losses associated with:
  1) Individual turbine power performance
  2) Frequent faults and other availability losses
- Through the monitoring of operating wind farm data, these losses can be quantified.
- Ultimately, regular monitoring will improve the performance of the entire wind farm.