Efficient Wind Farm Performance Analysis & Optimisation

Christopher Gray
November 2012
Contents

- Complete process
- Software & automated analysis
- Performance indices
- Detailed analysis
- Field inspection, corrective action
- Online Monitoring
- Continuous Improvement
- Summary
The root of the matter...

1) Energy Yield = f (Installed Capacity, Availability, Capacity Factor)

2) Capacity Factor = f (Wind Speed Probability Distribution, Power Curve)

3) Power Curve = $U^3 \times \rho \times 0.5 \times A \times Cp$

- Consider $\rho$ in analysis (pressure, temperature, humidity, altitude)
- Treat $U$ with care (measurement error, wake effects, turbulence, sheer, veer)
- Maximise $A$ (swept area) → avoid yaw offset
- Maximise $Cp$ (power coefficient) → avoid losses

Focus on reducing losses: aerodynamic, drivetrain, electrical system, transmission
Complete Optimisation Process

- A systematic process is required to efficiently identify and solve problems
- The main steps include analytical techniques as well as practical field work
- An investigative approach is required, applying technical understanding

The improvement process must be systematic and efficient to keep costs down
Software

- Efficient performance assessment to identify problem turbines
- Automated data processing, flexible reporting tools

Customised software tools support the analyst in root cause investigation
Top Level Analysis

- Turbine production ratio → energy produced at turbine vs expectation according to power curve
- Park production ratio → energy metered at grid connection vs expectation
- Automatic detection of outlier power curves (statistical Jackknife)
- Quantified energy loss due to non-optimised performance (below power curve)

### KPI Table

<table>
<thead>
<tr>
<th>Reference</th>
<th>KPI1</th>
<th>KPI2</th>
<th>KPI3</th>
<th>KPI4</th>
<th>KPI5</th>
<th>KPI6</th>
<th>KPI7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Year</td>
<td>Month</td>
<td>Windpark</td>
<td>Park production ratio</td>
<td>Worst single turbine production ratio</td>
<td>Power curve outliers</td>
<td>Average power range</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>%</td>
<td>(%)</td>
<td>(%)</td>
<td>(%) (Turbine Id)</td>
<td>(%) (of how many?)</td>
<td>[%]</td>
</tr>
<tr>
<td>2012</td>
<td>Jan</td>
<td>AET01</td>
<td>98.3</td>
<td>96.4 (12)</td>
<td>10 (20)</td>
<td>98.5</td>
<td>98.4 (13)</td>
</tr>
<tr>
<td>2012</td>
<td>Feb</td>
<td>AET01</td>
<td>99.1</td>
<td>98.0 (12)</td>
<td>10 (20)</td>
<td>98.5</td>
<td>96.3 (02)</td>
</tr>
<tr>
<td>2012</td>
<td>Mar</td>
<td>AET01</td>
<td>98.1</td>
<td>96.7 (12)</td>
<td>20 (20)</td>
<td>98.3</td>
<td>90.1 (02)</td>
</tr>
<tr>
<td>2012</td>
<td>Apr</td>
<td>AET01</td>
<td>99.7</td>
<td>98.8 (09)</td>
<td>20 (20)</td>
<td>97.9</td>
<td>98.5 (11)</td>
</tr>
<tr>
<td>2012</td>
<td>May</td>
<td>AET01</td>
<td>98.4</td>
<td>97.4 (09)</td>
<td>10 (20)</td>
<td>98.2</td>
<td>96.3 (07)</td>
</tr>
<tr>
<td>2012</td>
<td>Jun</td>
<td>AET01</td>
<td>98.5</td>
<td>97.4 (09)</td>
<td>10 (20)</td>
<td>98.7</td>
<td>97.5 (12)</td>
</tr>
<tr>
<td>2012</td>
<td>Jul</td>
<td>AET01</td>
<td>98.3</td>
<td>98.0 (09)</td>
<td>10 (20)</td>
<td>98.6</td>
<td>98.0 (18)</td>
</tr>
</tbody>
</table>

*KPI’s are automatically generated and analysed to quickly identify problem areas*
Multiple Data Sources

- Consider all available data sources, look for differences, check for known issues

- Monthly performance reports
- Power performance test reports
- Alarm records
- Vibration CMS
- Bill of Materials
- Sensor calibration certificates
- SCADA 10-Minute Logs
- Service history
- Resource assessment
- Control software versions & parameters
- Power curtailment
- Sensor specification

Various sources of information should be considered during investigative analysis
Bill of Materials

- Specification of main components should be ideally logged in a company-wide database.
- Queries can provide immediate information concerning specification or build differences.

Centralised information accessible via intuitive software saves time!
Power Curve Analysis

- Power curves should be corrected to account for air density effects (take care of altitude!)
- Filters should be applied to remove start-up / shut-down events
- Standard techniques: directional sector filtering, multi-turbine comparisons

*Power curve analysis should be carried out carefully and using corrected data*
High quality visualisation tools help the analyst to interpret multidimensional problems.
Sources of Uncertainty

- Wake effects, turbulence, sheer & veer, time constants
- Varying turbulence intensity across wind speed range
- Sensors strongly affected by wake of passing blades
- Wind speed sensors built for high reliability, some limitations in accuracy (+/- 0.5 m/s)
- Sensors can be adjusted via a lookup table (source: FT Technologies Ltd)

*Power curve analysis vs manufacturer power curve must be treated with care!*
Sensor inaccuracy

- Check anemometer accuracy using multiple variables
- Power, Pitch, Rotor Speed vs Wind Speed
- If offsets are similar in all parameters, sensor error is likely
- Power cross checks remove wind speed influence altogether

Monthly average power differences

Additional checks can improve confidence in results despite wind speed measurement issues
Windspeed Cross Checks

- Erroneous wind speed measurements can be detected by comparing with neighbours
- Example: compare the time series for each turbine with the median of the others
- Visualise distribution of “residual” using statistical box plots

Cross checks vs. neighbouring turbines can identify outlying windspeed measurements
Case Study (1)

Direct comparison of power vs neighbour turbine confirms loss of production

why is my turbine performing so badly?
Thorough desktop analysis can provide answers, avoiding expensive field work.
Field Inspection

- Based on data analysis and investigative work, derive an inspection programme
- Where possible, involve the OEM in the inspection process
- Bring the right tools for the job
- Examples of focus areas include
  - Alignment: pitch and yaw
  - Wind sensor condition and alignment
  - Generator settings (small stage, large stage)
  - Controller settings (noise limitation)
  - General condition of blades
- Systematically record findings in a database

Focused turbine inspection can reveal the root cause of performance problems
Correction

- Sometimes corrective measures can be carried out immediately, for example:
  - Realignment of wind speed / wind direction sensors
  - Blade pitch realignment
  - Noise control settings

- In some cases follow-up service activities may be required, such as:
  - Blade repairs
  - Sensor replacement
  - Pitch drive repair

- Often the close cooperation of the OEM is required, for example if:
  - The turbine is still under warranty
  - Software updates or modification to parameter settings is required

*Corrective measures range from simple, quick fixes to more complex component repairs*
Confirmation

- Performance analysis should be repeated to confirm successful optimisation
- IEC61400-12: 180h of data in total, at least 30 min in each bin. One month is preferable
- Recommended basis for benchmarking:
  - Power curve, before & after correction
  - Metered Energy vs neighbours, before & after correction (filter: all turbines running)

The effectiveness of performed corrective measures should be accurately quantified
Online Monitoring

- Online Monitoring of asset performance provides an early warning mechanism
- Software automatically calculates KPI’s and statistics, reporting only in case of problems
- Also power curves can be regularly analysed and monitored (daily)
- Note: an online system requires online, automated data validation!

Online Monitoring allows early intervention, reducing energy losses and maximising profitability
Visualisation

- A Geographical Information System provides a clear overview of the fleet health status

A clear and intuitive overview of the status of all assets supports rapid response
**Know-How Database**

- Know-how accumulated during successive projects should be systematically captured.
- Database of known problems, root causes, indicators and corrective measures.

### Performance Deficit

<table>
<thead>
<tr>
<th>System</th>
<th>Component</th>
<th>Root Cause</th>
<th>Performance Impact</th>
<th>Analysis Task</th>
<th>Recommended Field inspection</th>
<th>Corrective measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control system</td>
<td>Software</td>
<td>Incorrect noise control mode</td>
<td>Turbine running on incorrect power curve</td>
<td>Power curve analysis, rotor speed &amp; pitch map analysis</td>
<td>Check of controller parameterisation</td>
<td>Re-parameterisation of controller</td>
</tr>
<tr>
<td>Control system</td>
<td>Software</td>
<td>Software mismatch to hardware</td>
<td>Turbine aerodynamic or electrical efficiency not optimised</td>
<td>Power curve analysis</td>
<td>Check software versions and parameterisation</td>
<td>Update software or parameterisation to match hardware</td>
</tr>
</tbody>
</table>

---

*A centralised database for systematic know-how storage supports long term improvement*
Summary

- There is potential for performance optimisation of many turbines
- Problem areas need to be efficiently identified
- Custom built software supports effective analysis
- Focused inspection and corrective activities have been proven to bring results
- The optimisation activity provides technological insight, with positive side effects
- A know-how database provides a basis for long term improvement
- The optimisation process can be integrated into standard working practices