Optimising Cost of Energy - New and Existing Wind Farms

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Agenda

- Making the business case
  - LCOE
  - Improvements versus cost/time
  - Validating performance
- Layouts
  - Energy versus Cost of Energy optimisation
- Components
  - Example blade add-on vortex generators
- Control
  - Optimising start-up & yaw
  - Wake control
    - Pitching
    - Wake steering
- Conclusion
Making the Business Case
- LCOE, Considerations & Validation
Levelised Cost of Energy (LCOE) Driver Tree
Strongly depending on joint optimization

LCOE

Lifetime generation

- Gross AEP
  - Power curve
  - Hub height
  - Wind conditions at site
  - Wind farm efficiency
  - Wind forecast uncertainty
  - Further wind farm losses
  - Wind farm availability

Lifetime cost

- Investment costs
  - Wind turbine
    - Wind farm planning
    - Civil works
    - Electrical works
    - Transmission access
    - Interest during construction
    - Risk allocation

- Operating costs
  - Service / maintenance
  - Land lease
  - Operational management
  - Insurances
  - Transmission / marketing
  - Indexation
  - Retrofits

- Financing costs
  - Debt equity ratio
  - Interest rate
  - Term
  - Cost of equity

LCOE today influenced by

- Classic OEM scope
- Joint OEM and developer potential
- Developer scope

Notes:
- Wake effects
- Load management
- Cabling efficiency
- Substation efficiency
- Sound management
- Climatic losses
- WEC availability
- BoP availability
- Grid availability
Balance:

- Cost of change
  - Initial investment
  - Maintenance cost of change
  - For operating wind farms cost of downtime

- Effect of change
  - Increased Generation
  - Verification
Performance Validation

- Traditional individual turbine performance measurements
  - Meteorological masts and/or remote sensing devices are used to define free flow wind speed at hub height.
  - Power curves as measured according to IEC 61400-12 series
  - Measurement uncertainty around 5%
  - Difficult to capture smaller performance improvements and doesn’t capture wind farm performance (i.e. wake reductions)

- Wind farm performance
  - Senvion recommends a method based on differential yield measurements.
  - This can be purely SCADA based or include meteorological masts.
Layout Improvements
- Energy vs Cost of Energy Optimisation
LCOE layout optimisation

Biggest gains before wind farm planning permission:

- Balancing BoP costs and energy yields
- On high wind speed Annual Energy Production (AEP) and Levelised Cost Of Energy (LCOE) optimised layouts are very similar
- On lower wind sites good gains can be had by optimising for LCOE.
- For example on one recent Australian analysis for a site prior to planning approval the LCOE optimised layout compared to the AEP optimised layout within the project boundaries showed…
  - 1.3% decrease in AEP
  - 13 km reduction in road length
  - 18 km reduction in cable length
  - 0.6% improvement in LCOE
Component
Example of Blades
Example component improvement – vortex generators

Vortex generators

- Delay stall in root region of blade resulting in increased lift and increased AEP
- Can be installed on blades on existing turbines
- Typical improvements on MM92 of 0.7%. Best improvements on low wind sites.

Considerations

- Downtime for installation
- Including in maintenance regime
Control Improvements
- Examples Turbine Control Upgrade 1.0 and Senvion Park Control (Load Sharing & Wake Steering)
Turbine Control Upgrade 1.0

Bundle of performance enhancing products increasing AEP up to 1.3%
- Based on improved parameters and self-learning software algorithms
- Turbine Control Upgrade 1.0 comprises two features (Dynamic Yaw, Smart Turbine Start)

**Dynamic Yaw**
- Standard (wider) yaw angle
- Improved (smaller) yaw angle
- Reduces the acceptable "out of wind" angle
- Based on experience with operating turbines
- Improved balance between yaw activity and power output
- Turbine points into the wind more accurately
- Best improvement on simple to moderately complex sites

**Smart Turbine Start**
- Self-learning algorithm adapting to site specific conditions
- After each successful start of a turbine "Smart Turbine Start" reduces start-speed successively
- Unsuccessful start leads successive adjustment of start speed towards 3m/s

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Senvion Park Control (SPC) – Load Sharing

Reduction of axial induction factor through higher pitch angles

- De-rate turbines at leading positions with increased pitch angles during partial load

- Increased transparency of leading turbines

- Turbines on the wake can produce more as wake effects reduce

- Overall wind farm yield is increased, while loads are more distributed

- Increased Pitch
  - Decreased AEP
  - Decreased Loads

- Decreased Wake Loss
  - Increased AEP
  - Changed Loads

- Cumulative effect
  - Changed Wake Loss
  - Changed AEP
  - Changed Loads

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Gebraad et al. 2014

Wake steering away from neighbouring turbines through yaw misalignment

Gebraad et al. 2016
Full-scale field test behind an 80 m diameter (D) 1.5 MW turbine

Fleming et al. 2017
**Senvion Park Control (SPC)**

**Test case, 10 x 3.6M140 EBC**

- A desktop wake steering study has been done to identify the potential for Senvion Park Control
- Site specific input parameters used are the layout, turbine specifications and wind conditions.
- 3 maximum yaw angles are considered.
Senvion Park Control (SPC)

NO WAKE STEERING

WITH WAKE STEERING
Senvion Park Control (SPC)

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### OPTIMAL YAW ANGLE PER TURBINE FOR MAIN WIND DIRECTION 240°

<table>
<thead>
<tr>
<th>Optimization</th>
<th>Calculation resolution</th>
<th>Max yaw angle [°]</th>
<th>AEP increase [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12 sectors</td>
<td>± 5</td>
<td>0.4</td>
</tr>
<tr>
<td>2</td>
<td>12 sectors</td>
<td>± 10</td>
<td>0.6</td>
</tr>
<tr>
<td>3</td>
<td>12 sectors</td>
<td>± 25</td>
<td>0.9</td>
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</tbody>
</table>
Conclusion
Senvion can help clients make a business case for improvements based on LCOE

Improvements can be done at any stage of the project
- Layouts – ideally before planning
- Component improvements – before or after installation
- Control – before or after installation

Validation can be done by differential measurements between turbine groups with and without the improvement
Thank you for your attention

Senvion is currently recruiting
Visit Senvion Careers page for more information

Senvion
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