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Integrated Design & Optimization of Offshore Wind Farms

Design consideration based on a cost model

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Broomfield, CO
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Presentation content

- ✓ Introduction – What is integrated design
- ✓ Wind turbine / Wake
- ✓ Wind Farm control considerations
- ✓ Electrical system design considerations
- ✓ O&M modeling / design considerations
- ✓ Recommendations & Conclusion

Ecological issues are not considered, while the can influence the cost considerably!

Introduction – What is integrated design or system engineering.

Integrated design in the conventional sense is to bring designers from all disciplines together from the start of the project

Now a days it translated into coupling of proven design tools of all disciplines to and control the design process through a single interface to determine all factors of a target function.

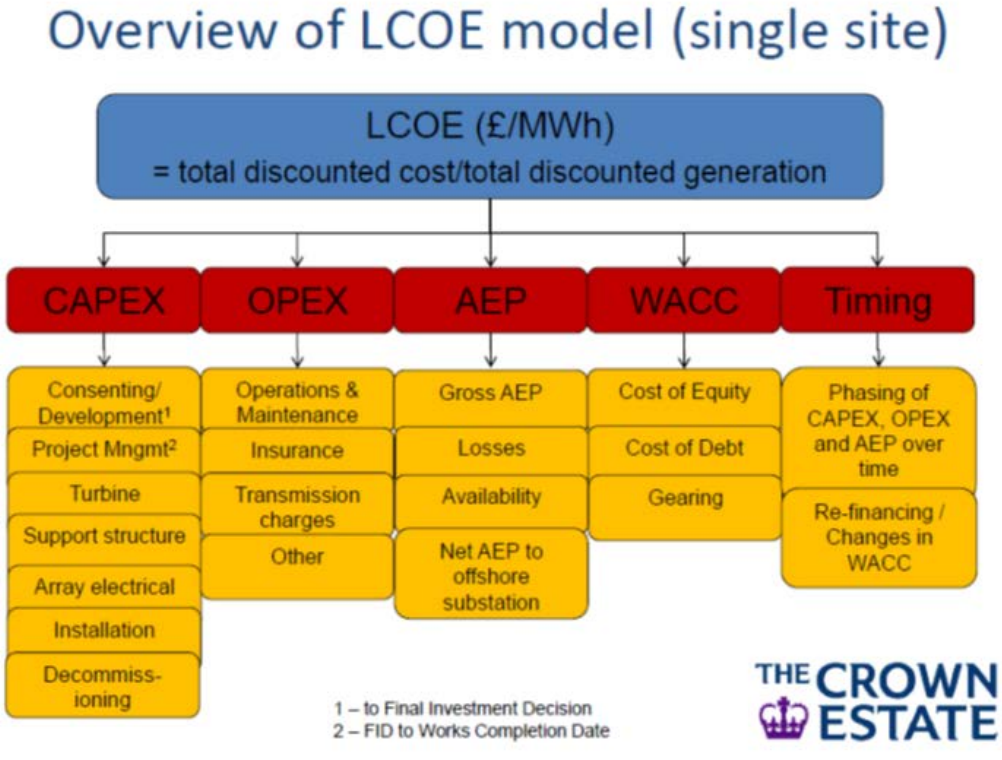
Benefits are:

- ✓ Cost reductions during the development / faster time to market
- ✓ Higher reliability of the design / less surprises during integration of the system
- ✓ Ultimately lower cost of energy

Cost of Energy

- ✓ The Cost of Energy is depending on a large number of factors or cost components.
- ✓ To evaluate the cost function it will be necessary to have (detailed) models of all major costs
- ✓ Some of these aspects are mentioned in the next slides

Just an example LCOE model, see model of the Crown Estate (UK)



Wind Farm – Wind turbine considerations

- ✓ In the past wind turbines were designed for solitary use
- ✓ Presently the majority of wind turbines are installed in wind farms

- ✓ This will lead to “another” wind turbine:
  - ✓ Different optimum for the rotor design, not the maximum energy capture of a single machine is important but maximizing the wind farms output is the target.
  - ✓ Different control, as well for the wind turbine as for the wind farm
  - ✓ Using grid demands for faster reactions and support of the grid stability
  - ✓ Etc.

Wind Farm - Wake losses considerations

Wind farm lay-outs are compared on the basis of:

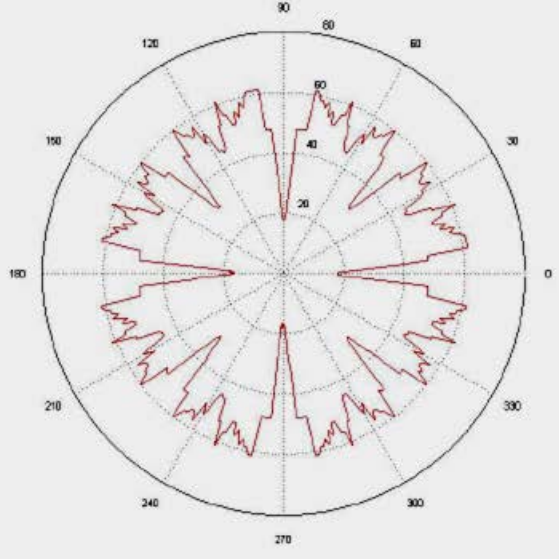
- ✓ Energy yield – wake losses
- ✓ Performance of the wind farm from grid operators point of view, e.g. variability of power[1] as function of wind direction changes.
- ✓ Wind farm induced (fatigue / extreme) loading

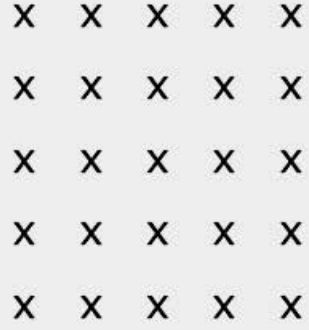
- ✓ Last but not least influences of (future) neighboring wind farms

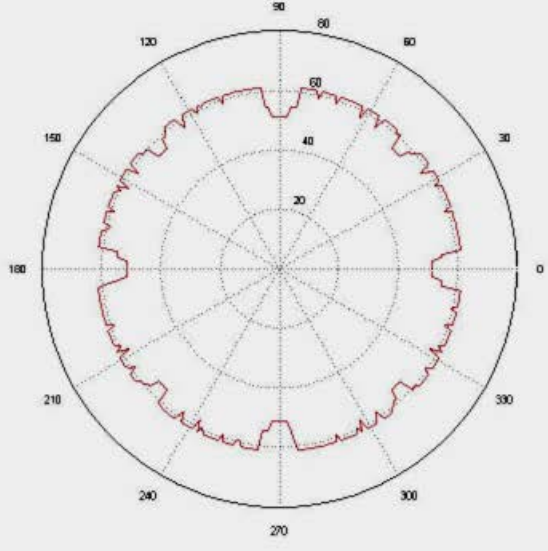
[1] See next slide

Wind Farm -
Wake losses considerations

Wind farm output and wind direction







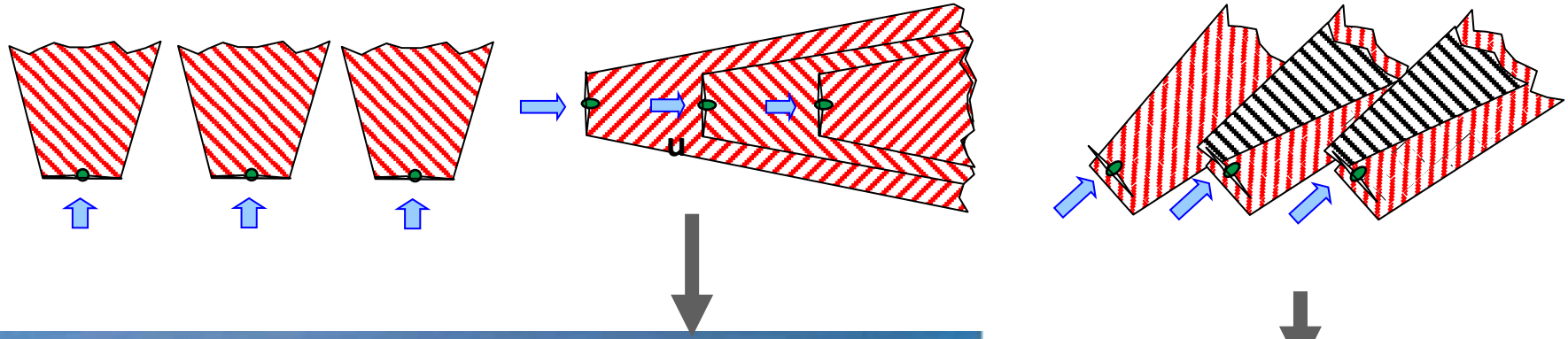
1% ambient t.int

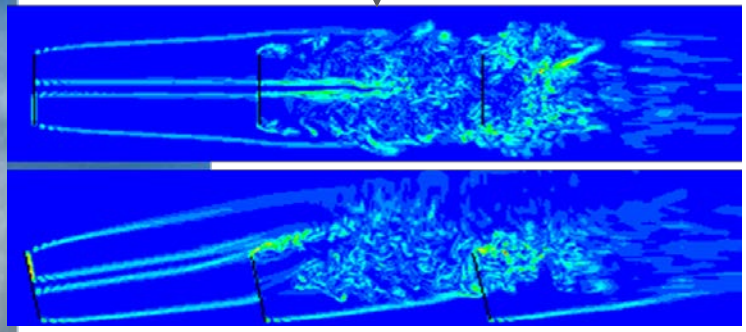
10% ambient t.int

High variability

Low(er) variability

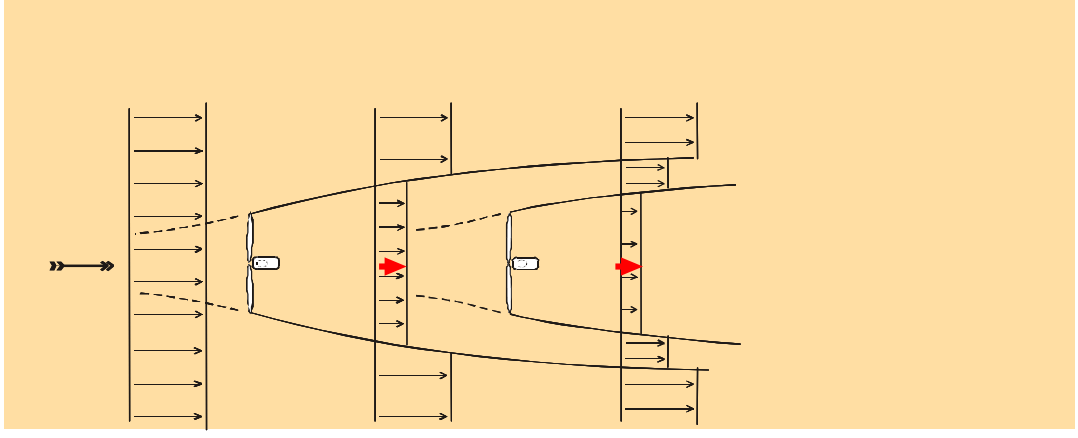
Wind Farm – control considerations

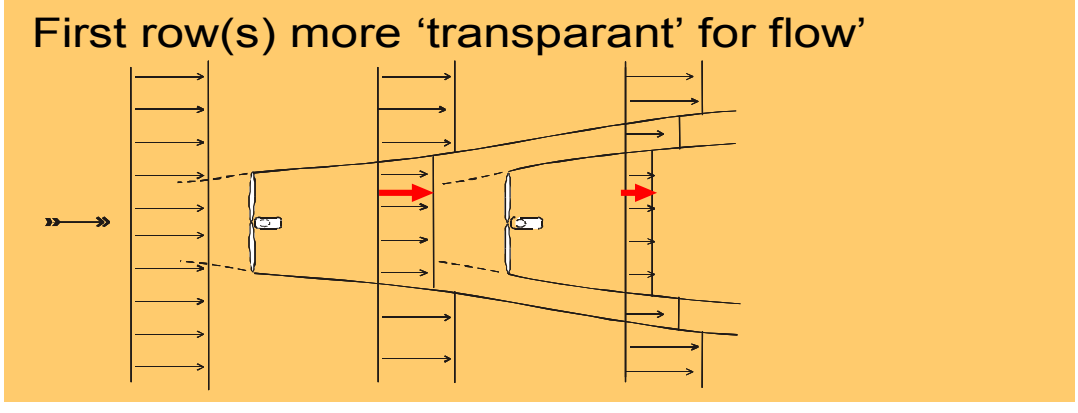




CFD Large Eddy Simulation

Wind Farm – control considerations





Increasing output
& decreasing variability
by power control

Wind farm – control considerations

With wind farm control the wind farm can be optimized for power / losses and loads.

The control target function is still not well determined and can also be different for different situations, e.g. depending on the spot market prices.

Functions could be

- ✓ Optimal energy yield (at what cost?)
- ✓ minimal fatigue damage per kWh per machine at certain power level or
- ✓ averaging the fatigue loading for each wind turbine over certain time period.

Electrical system design considerations

The electrical system is a substantial part of the capital cost of an off shore wind farm, depending on the distance to shore or the main grid.

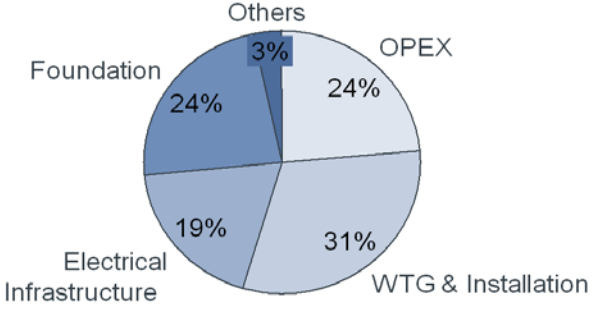
The cost and performance of the electrical system are influenced by:

- The lay-out of the wind farm
- The chosen concept for the electrical system inside the wind farm
  - Type of cables, transformers and convertors
  - Type of control inside the E-system of the wind farm, e.g. cluster control
- The distance to shore and the chosen concept of the transmission (AC – DC)
- Etc.

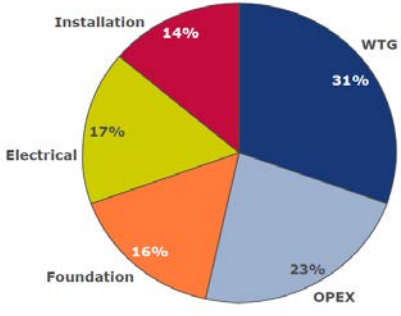
Choice made based on simulations, resulting in internal losses, and cost components database comparing all options, resulting in cost.

O & M considerations - key figures

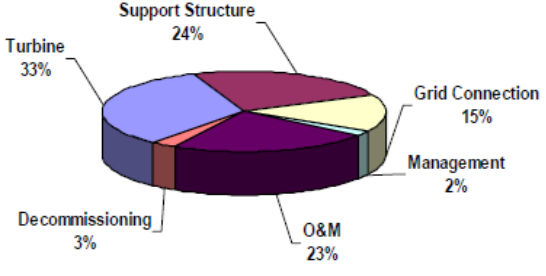
- Availability 90 to 97 % *(much lower during early days!)*
- Costs 20 to 35 €/MWh
- O&M costs 25 % of the kWh costs



Vestas, 2011



EWEA, 2011

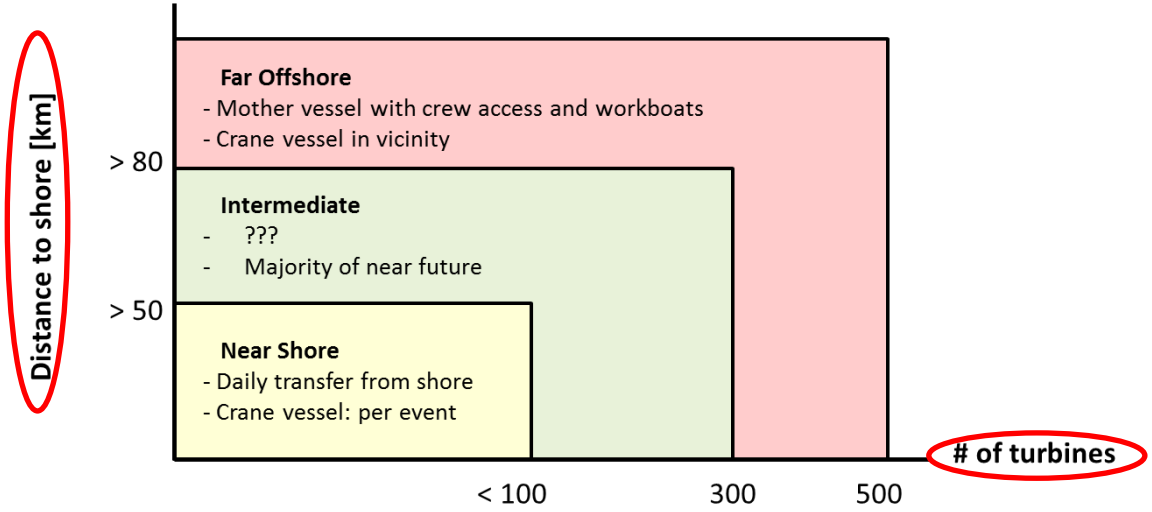


NREL

- Revenue losses approximately 50% of O&M Costs
  (and comparable with cost for corrective maintenance)

O&M: relation to farm design

- Maintenance concept
  - Distance to shore (wind farm location)
  - # turbines (wind turbine size for given farm size)
- Selection of equipment
  - Helicopter → helidecks on turbines and substations
  - Access vessel → number of boat landings on turbine

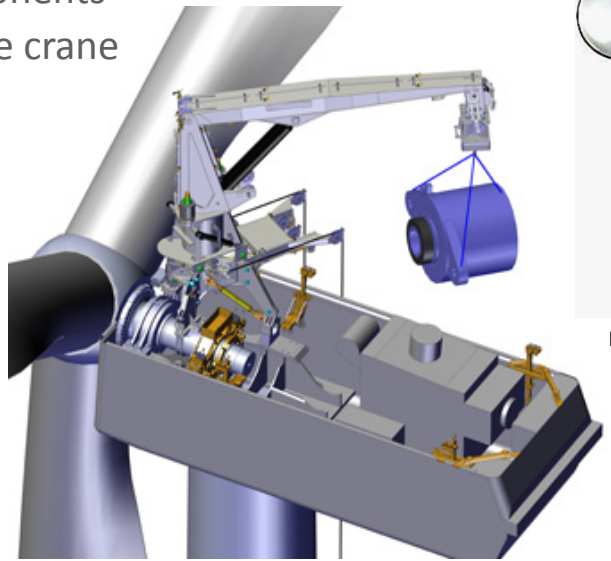


http://www.rechargenews.com/energy/wind/article325878.ece

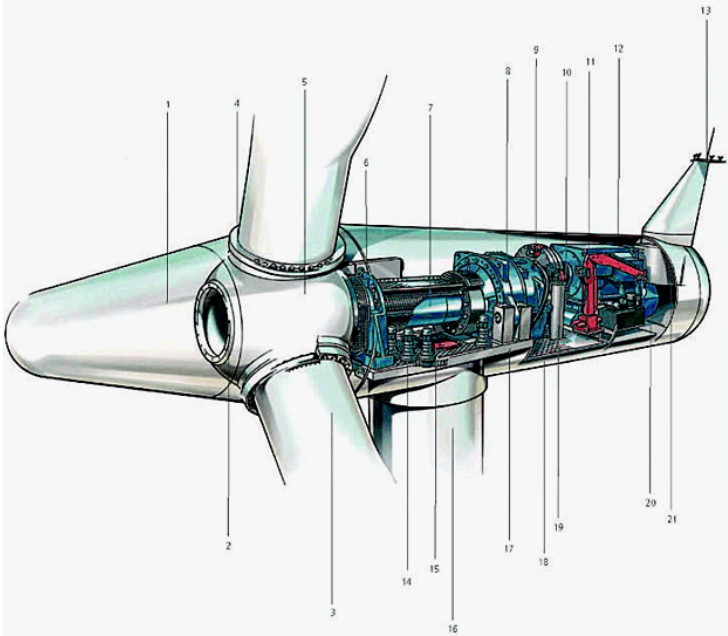
http://worldmaritimenews.com/archives/50747

O&M: relation to farm design

- Wind turbine reliability
  - Wind turbine type
  - Wind farm loads (wind farm control)
- Wind turbine maintainability
  - Modularity components
  - Capacity of nacelle crane



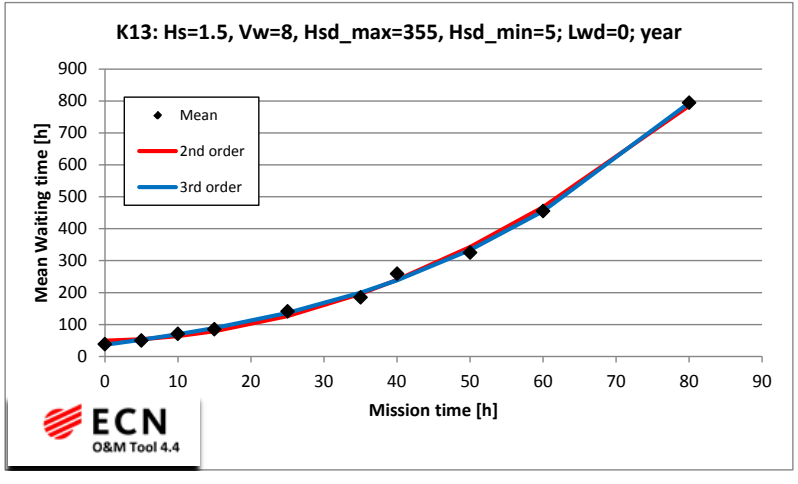
http://www.liftra.com/html/news_uk.html



http://electrical-engineering-portal.com/siemens-wind-turbine-swt-2-3-82

O&M: relation to farm design

- ✓ Characterization of weather conditions
  - Depends on wind farm location
  - Wind and wave climate in combination with weather limits equipment determine wind farm accessibility and weather downtime



http://gotpowered.com/2010/european-offshore-wind-weathers-the-storm/

Conclusion & Recommendations

1. There are already many sub (cost/performance) models available in a reasonable high level of detail.
2. However also still much is unknown during the design phase of a project, especially the more site specific items where the Balance of Station is one of the main unknowns with a high impact on the cost of energy.

3. As shown a lot of interaction is present, e.g. availability /reliability and O&M are strongly influenced by turbine and farm concept.

4. Major cost reductions can be still be achieved by reduction of project lead time and by reduction of risk resulting in lower capital cost!

Questions?

Thank you for your attention

ECN has many design tools available for wind farm design that can assist in modeling the Cost of Energy like:

- ✓ FarmFlow
- ✓ EE-Farm
- ✓ OM & Tool
- ✓ OM Cost Estimator

See:

http://www.ecn.nl/units/wind/rd-programme/integrated-wind-turbine-design/design-tools

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