Integrated Offshore Wind Farm Design: Optimizing Micrositing and Cable Layout Simultaneously

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Turbine Placement

*Algorithms may consider*
- wake modeling (commonly Jensen’s)
- additionally electrical component installation, surface concession, and environmental impact

*Types of algorithms used*
- classical Mixed Integer Programing
- non-classical: multi objective evolutionary, gradient search, greedy heuristic, genetic, simulated annealing and pattern search algorithms
- particle swarm used to consider non-conventional layouts

*Cable Installation Cost Considered?*
- not at all, or approximated using a heuristic (shortest spanning tree)

**Our Goal:**
- integrate turbine placement into mixed integer programing model for electrical layout optimization

Case Study: Barrow Offshore Windfarm

1. Wind speed deficits calculated for each pair of turbines

\[ \delta_{\text{total}} = \left( \sum_{i=1}^{n} \delta_i \right)^{\frac{1}{2}} \]

2. Deficit aggregated for each turbine across all turbines that impact it using sum of squares

\[ \delta = 1 - \frac{1 - C_t}{(1 + k_w x/r)^2} \]

Model uses Jensen’s Wake Model to approximate windspeed deficits at each turbine

- poor representation of wake characteristics, but good for approximating average wind deficits long term

**Method**

- sorted approximately 4 years of 10 minute wind data into 200 windspeed bins and 400 wind direction bins (pairs of bins weighted by proportion of corresponding data)
- used Jensen’s to approximate windspeed deficits at each turbine for each bin
  - wake expansion coefficient adjusted to reflect offshore wake expansion rate
- used windspeed deficits to approximate power production in each scenario
Generally, annual power output approximation can be approximated by weighting scenarios

- this doesn't accurately reflect cable ratings required to deliver turbine power
- k means algorithm used to cluster scenarios of similar turbine power output (5000 iterations, 20 windspeed scenarios developed)
  - mean turbine power output in each Jensen run used to determine scenarios
- scenarios given weights based on weights of Jensen runs present in each scenario
- scenarios each have associated power output for each turbine
Select Turbine Layouts to be compared
  - Standard schemes but variable spacing
  - Swarm model outputs

Model Wakes for each scheme to calculate wake cost
  - Jensen’s model

Integrate wake cost into MIP and allow MIP to select optimal turbine spacing while determining cable selection
  - Can choose which cable connections to consider
  - Can integrate other costs into objective function
  - Integration of wake cost into objective function is non-trivial

Determined Pre-model
Low Computational Intensity (1 hour per run)
High Computational Intensity (6-10 hours per run)
Included in optimization of Case Study
- Cable installation selection
- Cable type selection
- Transmission system selection (MVAC, HVAC, HVDC)
- Wake cost of varies layouts
- Component failure rates
- Turbine spacing for turbine placement pattern selected
- Surface concession costs

Not included in case study, but model is equipped to handle
- Turbine placement scheme comparison
- Losses from electrical flow through cables

Not considered
- Non-standard turbine placement
- Macrositing
Optimized Layout

- Fewer 300 MW cables
- Two 60 MVA transformers instead of a single 120 MVA transformer
Well Modeled Components of the Objective Function

- Explained by interaction of windspeed deficits and turbine power curve
- Both have R squared values above .99
- Modeling issue is power not served cost
Overview
- Investment cost increased by 160,000 euros per year
- Power not served remained constant
- Surface concession cost increased by 100,000 euros per year
- 550,000 euros per year savings from wake decrease
- Net 300,000 euros per year savings, or 6 million euros over the life of the plant
We have created a robust model
- can be used to directly compare different layout schemes
- can be used to directly compare same layout scheme at variable spacing
  - different layout schemes can then be compared using tradeoff curves
- easy to incorporate costs associated with each turbine spacing considered into model

Wholistic optimization approach necessary to take full advantage of windfarm potential
- Tradeoffs may be too complex to predict without integrated optimization (power not served)
- but there is some promise here because of easy modeling of major Barrow objective function components
- is this true for all turbine layout schemes?