Wind Farm Layout Optimization Case Studies 3 & 4

IEA Task 37 on System Engineering in Wind Energy

Nicholas F. Baker, Andrew P. J. Stanley, and Andrew Ning
Brigham Young University, Provo, Utah, USA
Katherine Dykes
National Renewable Energy Laboratory, Golden, Colorado, USA

April 3, 2019

1 Introduction

Two major factors that affect wind farm layout optimization are 1) the optimization approach and 2) the wake model. We have thus far conducted two case studies to analyze differences in these variables, this document defines a third and fourth case study to further study these factors when given more realistic wind farm boundaries. Case study 3 (cs3) presents a scenario with a concave boundary. Case study 4 (cs4) presents a scenario with both concave boundaries and discontinuous boundary regions. For cs3 and cs4, the user is free to choose both optimization approach and wake model.

Participants will (1) optimize turbine locations to maximize annual energy production, (2) submit solutions with details regarding their optimization convergence and methodology. After all submissions are received, participants will be expected to perform a cross comparison of other participant solutions. Data will be consolidated, processed, and made available to all participants.

2 Problem Definition

Objective

The objective of each scenario is to maximize annual energy production, which we define simply as the expected value of aerodynamic power. For cs3 and cs4, the wind resource is supplied in 120 bins. Each bin has a specific directional probability and continuous wind speed distribution derived from Weibull parameters. Participants are free to use all, fewer, or interpolate more n directional bins for their optimizations if they wish. In other words:

$$AEP = 8760 \frac{\text{hrs}}{\text{yr}} \sum_{i=1}^{n} \sum_{j=1}^{m} f_i w_j P_{i,j}$$

where $P_{i,j}$ is the power produced for wind direction i at wind speed j, f_i is the corresponding wind direction probability, and w_j is the windspeed sampled from the given continuous Weibull distribution.

Design Variables

The design variables are the (x, y) locations of each turbine, all hub heights (z values) will be the same in cs3 and cs4. Every turbine in the farm is identical, and defined below in **Parameters**.

Constraints

In case studies 1 and 2, all farm boundaries were uniformly circular and centered on the origin. To make cs3 and cs4 more realistic, all boundaries are non-uniform and cs4 is made up of discontinous regions. It is based on the Borselle III and IV wind farms, and our version is depicted graphically in Figure 1. The coordinates for the boundary verticies are given in `iea37-cs3-boundary.yaml` and `iea37-cs4-boundary.yaml`. All turbine rotor radii must remain completely on or within this boundary. No turbine hub can be less than two rotor diameters from any other hub.

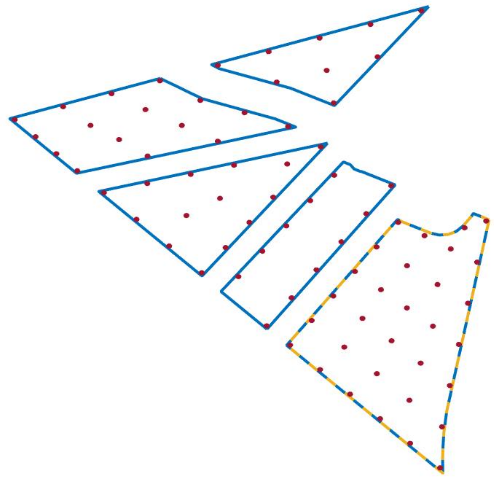


Figure 1: Graphic depiction of wind farm boundary for cs3 (outlined in yellow) and cs4 (outlined in blue). An example layout of turbines for cs4 is placed in red, with rotor radii to scale.

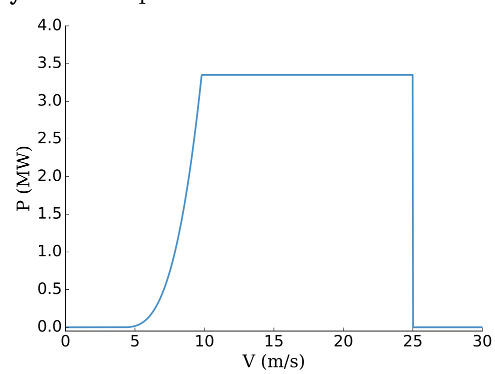
Parameters

The wind turbine is the IEA37 10 MW offshore reference turbine [1] with the following characteristics:

Rotor Diameter	198.0	m
Turbine Rating	10	MW
Cut-In Wind Speed	4	m/s
Rated Wind Speed	11	m/s
Cut-Out Wind Speed	25	m/s

All turbine data is also contained in the enclosed `iea37-10mw.yaml`. The power curve is defined as:

$$P(V) = \begin{cases} 0 & V < V_{\textit{cut-in}} \\ P_{rated} \cdot \left(\frac{V - V_{\textit{cut-in}}}{V_{rated} - V_{\textit{cut-in}}} \right)^3 & V_{\textit{cut-in}} \leq V < V_{rated} \\ P_{rated} & V_{rated} \leq V < V_{\textit{cut-out}} \\ 0 & V \geq V_{\textit{cut-out}} \end{cases}$$



The wind speed for each bin is given as a continuous distribution derived from provided Weibull parameters. The distribution is calculated as:

$$w = \frac{k}{\lambda} \left(\frac{x}{\lambda} \right)^{k-1} e^{-(x/a)^b}$$

Where x is the windspeed in m/s and w is the probability of that wind speed to occur. The variable k is the Weibull shape parameter and λ is the Weibull scale parameter.

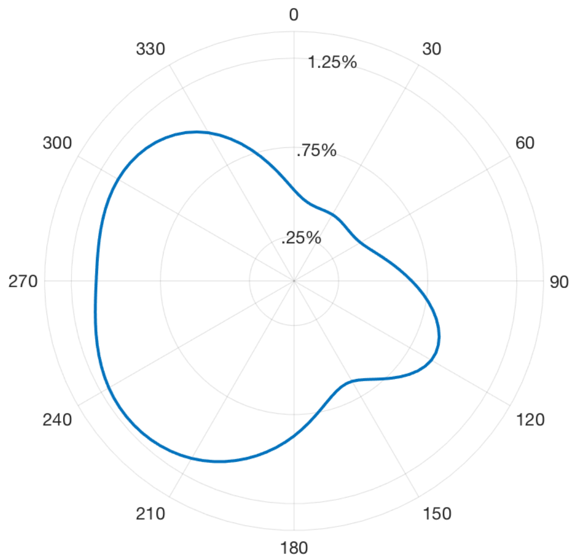


Figure 2: Wind frequency distribution over the 120 bins for the windrose used in cs3 and cs4.

The +y axis is coincident with 0°, and the CW wind rose is tabulated in `iea37-cs3-windrose.yaml`, depicted pictorially in Figure 2.

2.1 Baseline Layouts

Since both the files supplied to users necessary for participation, as well as the resulting output provided by each participant are in very precise formats, baseline layouts for both case studies are supplied. These files are called `iea37-cs3-ex-opt.yaml`, `iea37-cs4-ex-opt.yaml`, and `iea37-cs3-ex-log.yaml`. Like the example layouts provided for case studies 1 and 2, this baseline layouts are meant to provide a reasonable minimum output against which results can be measured. Participants are not required to use the baseline layouts as starting points for their optimizations, though they are permitted to do so.

Users participating in cs3 and cs4 will use their own wake model (thus the specific model-computed AEP values in the `.yaml` files will vary), but the baseline layouts are supplied as example submissions, to understand the specific `.yaml` reporting format we require.

2.2 Case Study 3

This problem defines a scenario where the user is free to choose both the optimization algorithm and the wake model. This single wind farm scenario is twenty-five (25) turbines with a boundary containing concavities. The boundary is depicted graphically (outlined in yellow) in Figure 1 and verticies are explicitly defined in `iea37-cs3-boundary.yaml`.

2.3 Case Study 4

This problem adds discontinuous boundary regions to the problem presented in cs3. The user is free to choose both the optimization algorithm and wake model. It is requested that participants use the same algorithm and model that they used in cs3 in order for us to observe scalability differences, but users are not required to do so. This single wind farm scenario is eighty-one (81) turbines with a boundary containing concavities and discontinuities. The participant or their optimization algorithm is to determine placement of all eighty-on turbines across the five boundary regions, there is no region apportionment criteria. The boundaries for cs4 are graphically depicted in Figure 1 outlined in blue, and verticies are explicitly defined in `iea37-cs4-boundary.yaml`.

3 Reporting and Evaluation

Participants will submit:

1. Optimal turbine placement solution using the `.yaml` format from the enclosed example layouts.
2. Optimization timing and convergence metrics using the `.yaml` format from the enclosed example logs.

Note that your `.yaml` submissions must report both total farm AEP, and farm AEP for each of your chosen binned wind directions, as in the enclosed `iea37-cs3-ex-log.yaml` example.

3.1 Reporting

Since results will be analyzed mainly through cross-comparison, submissions must adhere to the `.yaml` format in order to receive a ranking. You will submit two (2) files per case study: one with your optimized turbine layout, the second a log of your convergence data. Your submitted files should be named:

```
iea37-cs#-yourname-opt.yaml
iea37-cs#-yourname-log.yaml
```

Where:

- "`cs#`" is the case study number of the submission ("cs3" or "cs4").
- "`yourname`" is your personal or organizational name, all lowercase with no spaces or punctuation.
- `-opt.yaml` describes only the (x,y) coordinates for your optimal layout.
- `-log.yaml` contains information regarding your hardware and optimization algorithm's performance.

The following three files must be referenced internally by your submission, as is done by the example files:

- `iea37-10mw.yaml` lists the turbine data for the used IEA37 10 MW offshore reference turbine.
- `iea37-cs3-windrose.yaml` describes the wind speeds and frequencies used in both case studies.
- `iea37-cs#-boundary.yaml` which gives the vertex outline of the wind farm boundaries.

As shown in the example log given in `iea37-cs3-ex-log.yaml`, (1) number of target function calls and (2) intermittent AEP calculations at each iteration will be required. This means participants must log the intermittent AEP calculations and number of function calls at **each** iteration through the optimization process, in order for us to study trends regarding time to convergence.

Your optimal turbine layouts will be submitted following the examples of `iea37-cs#-ex-opt.yaml`. These will also be the formats supplied to you for the cross-comparison portion of participation, so ensure your submitted files are formatted correctly, and your automated readers understand the syntax.

3.2 Evaluation

Because the participant wake models are intended to differ, determining a "best" solution is generally not possible. Comparisons will be made using a cross-comparison approach, as was done in case study 2. Every participant will evaluate every other participant's solutions using their own wake model(s). It is essential that the `.yaml` format is adhered to so that cross-comparisons are painless.

4 Enclosures

Files included with this document, needed for full participation in the case studies are:

- `iea37-10mw.yaml` - data for the reference turbine used in both cs3 and cs4
- `iea37-cs3-windrose.yaml` - 120 bins, windspeeds given as Weibull distributions, for cs3 and cs4
- `iea37-cs3-boundary.yaml` - the vertices for cs3's wind farm's boundary
- `iea37-cs4-boundary.yaml` - the vertices for cs4's wind farm's boundary
- `iea37-cs3-ex-opt.yaml` - baseline layout for cs3, template for your submitted optimal turbine layout
- `iea37-cs4-ex-opt.yaml` - baseline layout for cs4
- `iea37-cs3-ex-log.yaml` - example of optimization results, denoting timing and iteration analysis

References

[1] Bortolotti, P., Dykes, K., Merz, K., Sethuraman, L., and Zahle, F., "IEA Wind Task 37 on System Engineering in Wind Energy, WP2 - Reference Wind Turbines," Tech. rep., National Renewable Energy Laboratory (NREL), Golden, CO., May 2018.