IEA Task 37 on System Engineering in Wind Energy
The Wind Farm
Combined Wake Model and Optimization
Case Study

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1 Introduction

This document defines a simple wind farm layout optimization collaborative case study. Participants are directed to use whichever combination of wake model and computational optimization strategy they choose, with the goal of obtaining the maximum Annual Energy Production (AEP) for the defined turbine field. In this case study the wind farm boundaries, directional wind frequency, and wind turbine attributes are fixed. Participants are to implement their choice of engineering wake model and optimization method, and use them to discover optimal turbine locations.

Participant results will be compared on two criteria:

1. **Quality:** Which wake model/optimization method reports turbine locations that return the highest comparative LES calculated AEP.

2. **Accuracy:** Which wake model/optimization method calculates an AEP that most closely matches the AEP calculated by an LES for the same turbine locations.

The goal of this collaboration is to compare participant results when using different combined wake model and optimization method strategies, in order to understand the performance differences due to choice of wake model and optimization algorithm selections. While the provided wind farm scenario is very simple, we expect the results to assist researchers in understanding the differences that occur due to implementation of various wake models and optimization methods. A greater understanding of the trade-offs of model and optimization selection for this simplified problem is expected to aid in solving and interpreting the results of more complex and realistic problems.

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2 Problem Definition

2.1 Wind Farm Definition

- The wind farm consists of nine turbines, boundary radius of 1,100 m.
- If necessary, the turbulence intensity is 0.075.
- Assume the freestream wind speeds given in this document are at hub height. If you need a wind shear, use a power law relationship with a shear exponent of 0.15.

The wind farm boundary is circular, as depicted Fig. 1. The origin is at the center of the field, coincident with the depicted NREL 5MW reference turbine (whose attributes are summarize in Appendix A). The specified boundary distance of 1100 m is measured as a radius from the origin. Note that the field boundary restricts turbine hub locations. The blade radius is permitted to extend beyond, but hub locations must be on or within the boundary. Hub locations are further restricted from being placed closer than two diameters apart from each other.

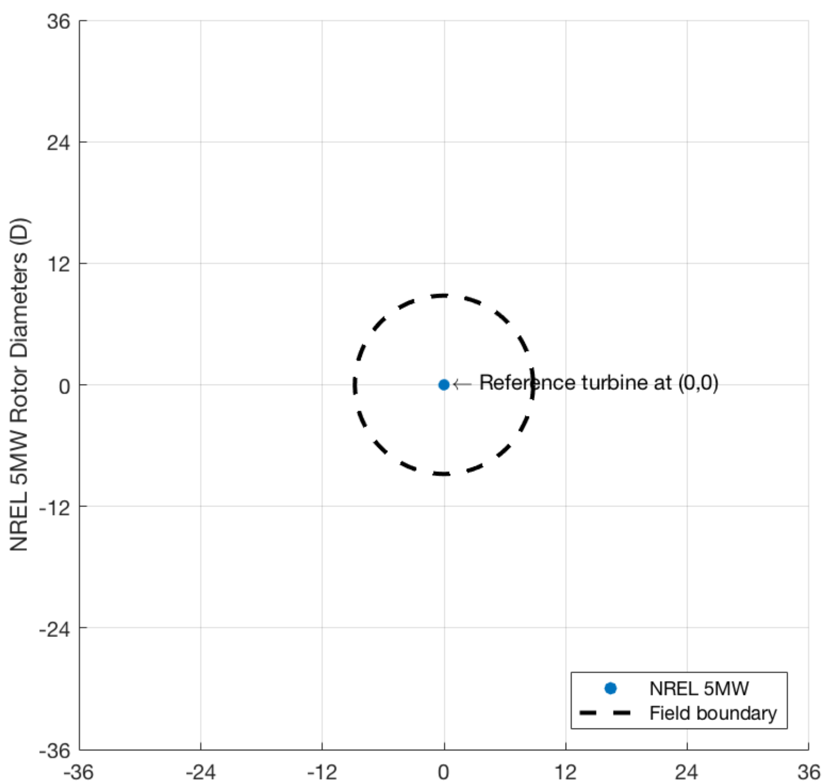


Figure 1: Depiction of circular farm boundary, reference turbine (to scale) placed at origin.

2.2 Baseline Layout

To assist in comparison of results, a baseline wind turbine layout is supplied. To assist in results comparison, you are to report the AEP calculated for this static turbine layout, as explained in

Section 3.1. You are also to conduct a single baseline optimization from this starting layout, and report your resulting optimized turbine locations with resultant AEP value. You are not required to start each of your optimizations from this baseline layout, only report the results from a single run using this baseline layout. For your other optimization attempts, feel free to use random starts, warm starts, intuition, or any other selection method you choose to initialize turbine locations.

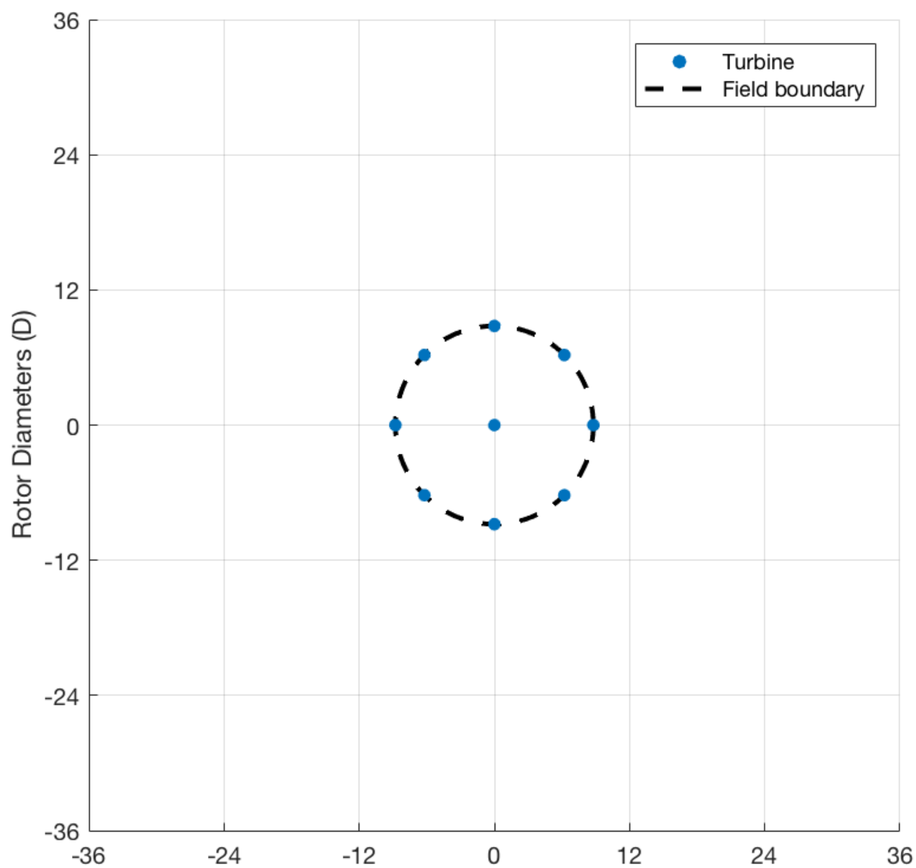


Figure 2: Baseline turbine locations (to scale) are only to be used for a single optimization run, and will assist in results comparison. Coordinates are located in Appendix B

3 Reporting Results

3.1 Submission Contents

You will submit both a `.txt` file with the requested turbine data, and a `.pdf` file containing a short description of your method/process. Both files are described below.

3.1.1 Turbine Data

Text file containing your:

- Baseline AEP (MWh)
- Optimized AEP from baseline (MWh)
- Initial AEP (MWh)
- Optimized AEP (MWh)

As well as:

- Optimized turbine locations from baseline (m)
- Initial turbine locations (m)
- Optimized turbine locations (m)

The initial AEP and turbine locations should be from the starting point of your submitted optimized layout, whatever method you use.

The baseline locations were designed using a minimum dispersion of 5 rotor diameters between each turbine. The turbine locations for the baseline arrangement is given in Appendix B, and is depicted graphically in Fig. 2.

3.1.2 Method Description

The `.pdf` file containing a short description of the relevant details of your method/process should include (at a minimum):

- Wake Model
  - Model name
  - Governing wake equations (if possible)
  - Description of general model shape (i.e. smooth, flat, Gaussian curve, presence of discontinuities, etc.)
  - What factors are accounted for by your model (i.e. partial wake, shear, turbulence, etc.)
  - Paper citation for description of model (if applicable)
  - Other relevant wake model details
- Optimization algorithm (including version and any non-default settings or modifications)

  - Name of algorithm
  - General type of algorithm (e.g. gradient-free, gradient-based)
  - Specific algorithm type (e.g. particle-swarm, genetic-algorithm, sequential quadratic programming, etc)
  - If you used a gradient-based method, how did you obtain the gradients.
  - Number of AEP function calls
  - Programming language(s) utilized
  - Other relevant algorithm details
- Computer hardware specifications
  - Manufacturer/Model/Speed of processor (GHz)
  - Number of cores utilized
  - System total RAM
- How you decided on the starting turbine locations for your final optimized results
- Time required for optimization convergence
- Links to relevant code(s) (if possible)
- Other details you consider relevant
- Bibliography

3.2 Submission Format

All submission materials should be submitted in a single compressed `.zip` directory. The directory should contain:

1. A `.pdf` of the method/process description as described in Section 3.1.2
2. A `.txt` file with the quantitative optimization results in the following format:

The text file should contain two sections: 1) for the baseline, optimized baseline, initial, and optimal AEP values and 2) for the turbine numbers and their corresponding optimized baseline, initial and optimized x and y locations. Entries in each row should be comma separated. All numbers should be in full double precision. Please see the example provided in Fig. 3:

```
# base AEP (MWh), opt base AEP (MWh), initial AEP (MWh), opt AEP (MWh)
AEP_base, AEP_base_opt, AEP_init, AEP_opt

# turb num, x_base_opt(m), y_base_opt(m), x_init(m), y_init(m), x_opt(m),
y_opt(m)
0, x0_base_opt, y0_base_opt, x0_init, y0_init, x0_opt, y0_opt
1, x1_base_opt, y1_base_opt, x1_init, y1_init, x1_opt, y1_opt
2, x2_base_opt, y2_base_opt, x2_init, y2_init, x2_opt, y2_opt
3, x3_base_opt, y3_base_opt, x3_init, y3_init, x3_opt, y3_opt
4, x4_base_opt, y4_base_opt, x4_init, y4_init, x4_opt, y4_opt
5, x5_base_opt, y5_base_opt, x5_init, y5_init, x5_opt, y5_opt
6, x6_base_opt, y6_base_opt, x6_init, y6_init, x6_opt, y6_opt
7, x7_base_opt, y7_base_opt, x7_init, y7_init, x7_opt, y7_opt
8, x8_base_opt, y8_base_opt, x8_init, y8_init, x8_opt, y8_opt
```

Figure 3: Optimization results text file example

A Wind Turbine Definition

The wind turbine used in this study is the NREL 5MW reference turbine [1]. The important parameters are:

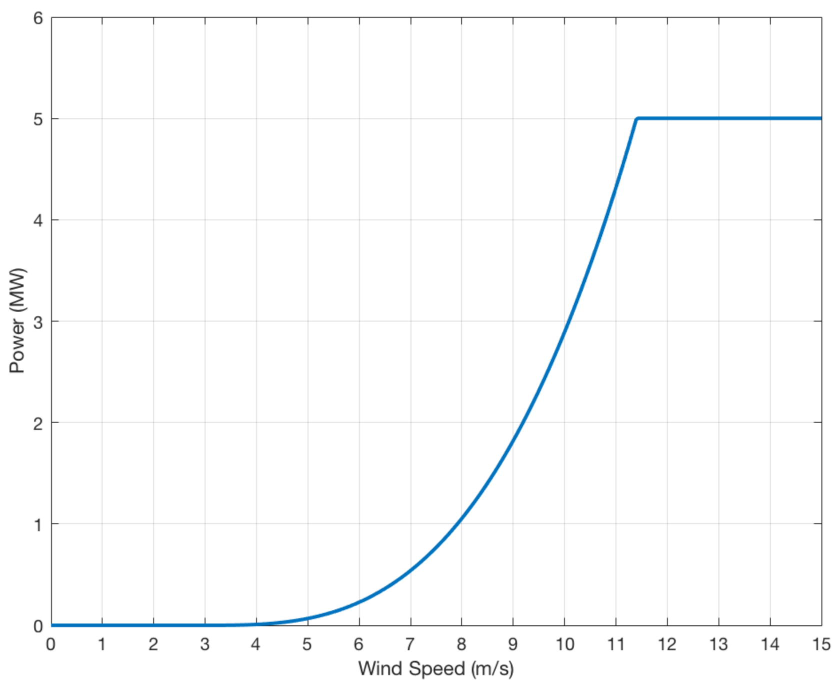
Table 1: NREL 5MW Reference Turbine key attributes [1]

Rotor Diameter	126.4	m
Turbine Rating	5	MW
Cut-In Wind Speed	3	m/s
Rated Wind Speed	11.4	m/s
Cut-Out Wind Speed	25	m/s

The power curve equation is given in Eq. (1) and graphed in Fig. 4.

$$P(U) = \begin{cases} 0 & U < V_{\textit{cut-in}} \\ P_{rated}\left(\frac{U - V_{\textit{cut-in}}}{V_{rated} - V_{\textit{cut-in}}}\right)^3 & V_{\textit{cut-in}} \leq U \leq V_{rated} \\ P_{rated} & U > V_{rated} \end{cases} \tag{1}$$

Figure 4: Calculated NREL 5MW reference turbine power curve



B Baseline Turbine Coordinates

(16) Turbine Wind Farm		
#	x (m)	y (m)
0	0	0
1	884.80	0
2	442.40	766.26
3	-442.40	766.26
4	-884.80	0
5	442.40	-766.26
6	442.40	-766.26
7	1769.60	0
8	1355.59	1137.48
9	307.29	1742.72
10	-884.80	1532.52
11	-1662.88	605.24
12	-1662.88	-605.24
13	-884.80	-1532.52
14	307.29	-1742.72
15	1355.59	-1137.48

C Wind Farm Attributes

C.1 Wind Speed

For this scenario, the freestream wind velocity will be constant throughout the farm, at 13 m/s, regardless of turbine location or time of day.

C.2 Wind Direction Probability

For the above specified wind speed, wind direction probability will mimic those found in a geographically linear canyon, using a bi-modal Gaussian distribution. This distribution is defined in Eq. (2) and the wind rose is shown below:

$$
\begin{aligned}
F =& w_1\left(\sqrt{\frac{1}{2\pi\sigma_1^2}}\right)\exp\left(-\frac{(\theta-\mu_1)^2}{2\sigma_1^2}\right) \\
&+ w_2\left(\sqrt{\frac{1}{2\pi\sigma_2^2}}\right)\exp\left(-\frac{(\theta-\mu_2)^2}{2\sigma_2^2}\right) \\
&+ w_2\left(\sqrt{\frac{1}{2\pi\sigma_2^2}}\right)\exp\left(-\frac{(\theta-\mu_3)^2}{2\sigma_2^2}\right)
\end{aligned} \tag{2}
$$

Where:

- θ: wind direction where north is 0°, measured clockwise.
- μ_1: first dominant wind direction (180°).
- μ_2, μ_3: second dominant wind direction (350° and −10°, respectively).
- σ_1: first standard deviation (20°).
- σ_2: second standard deviation (40°).
- w_1: first distribution weight (0.5).
- w_2: second distribution weight (0.5).

The wind rose shown below is a graphical depiction of the frequency from which direction on a compass (in degrees) the wind comes. A farther distance from the origin indicates a higher frequency.

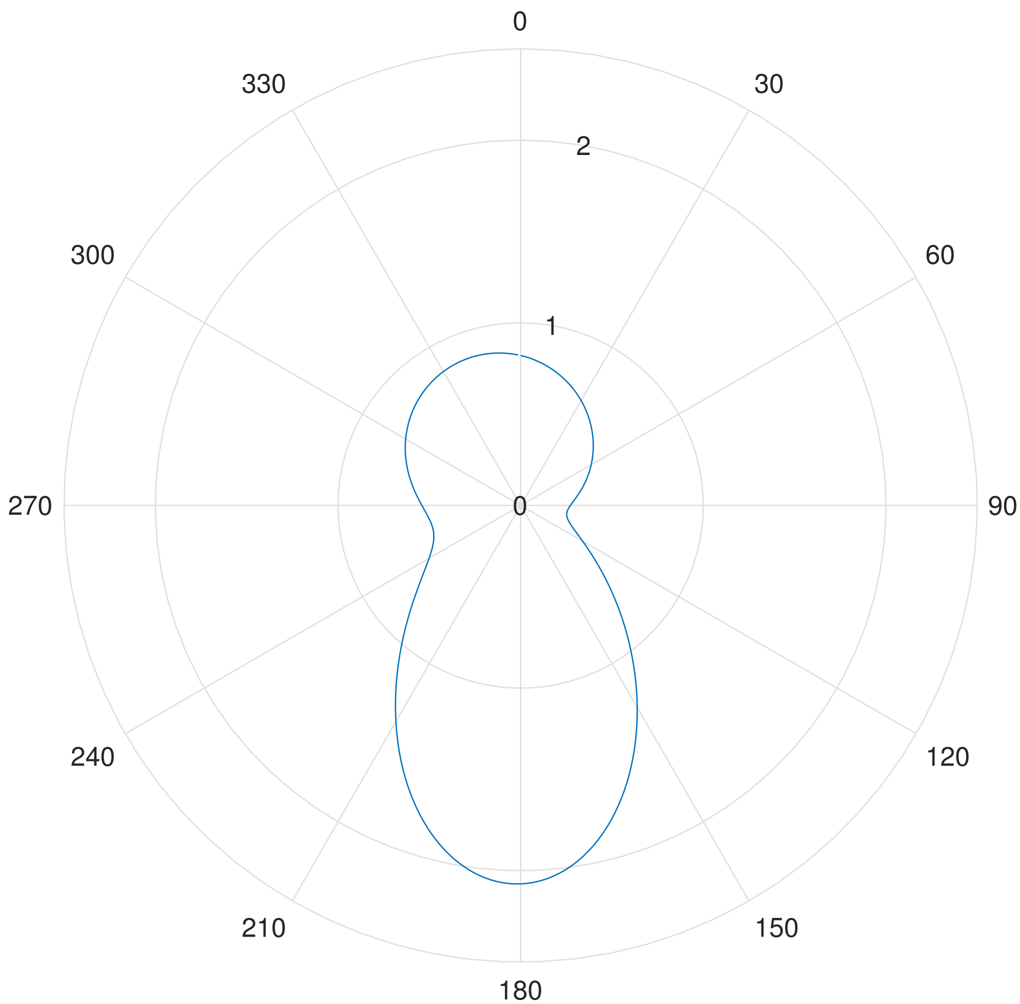


Figure 5: The wind frequency distribution; a bi-modal Gaussian distribution as defined in Eq. (2)

References

[1] Jason Jonkman, Sandy Butterfield, Walter Musial, and George Scott. Definition of a 5-MW reference wind turbine for offshore system development. Technical report, National Renewable Energy Laboratory (NREL), Golden, CO., 2009.