IEA Task 37 on System Engineering in Wind Energy The Wind Farm Optimization Only Case Study

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1 Introduction

This document defines a simple wind farm layout optimization problem of varying sizes, with the goal of comparing the results obtained when using different optimization methods for a single wake model. While the optimization problem is very simple, we expect the results to assist researchers in understanding the differences that occur due to optimizing wind farms using various numerical methods. The results are expected to serve as a benchmark for future wind farm layout optimization studies. The greater understanding of this simplified problem is expected to aid in solving and interpreting the results of more realistic problems.

2 Problem Definition

2.1 Wind Farm Definition

There are three (3) wind farm size scenarios which will be optimized:

1. Wind farm of sixteen (16) turbines, boundary radius of 2,000 m.
2. Wind farm of thirty-six (36) turbines, boundary radius of 3,000 m.
3. Wind farm of sixty-four (64) turbines, boundary radius of 5,000 m.

For all wind farm sizes, the following hold:

- The wind farm boundary is circular. The specified boundary distance is a radius from the origin.
- 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.

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2.2 Wind Turbine Definition

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

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

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

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

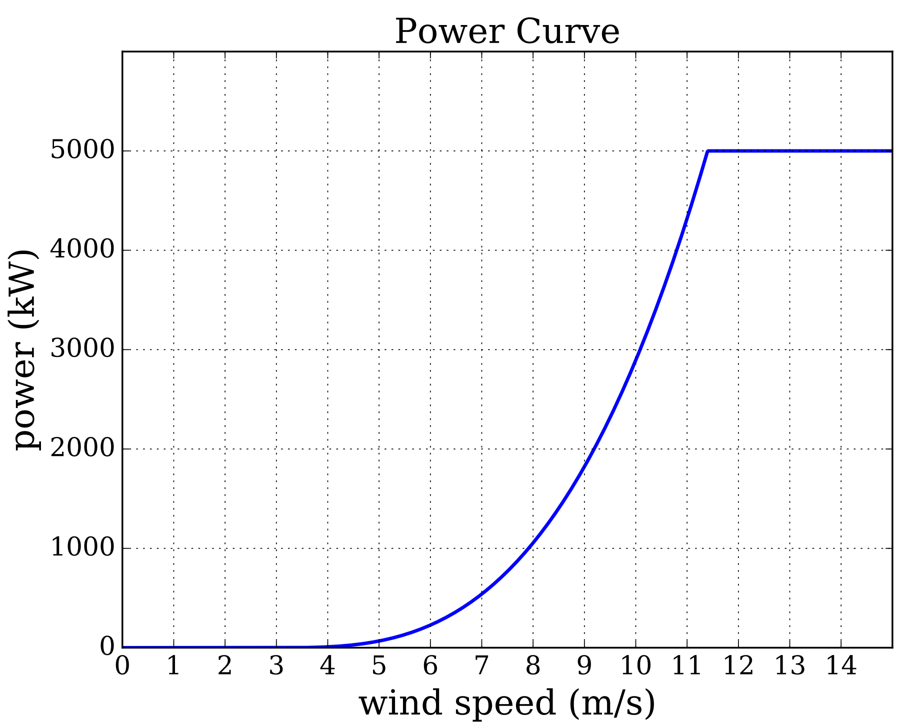

Figure 1: The wind turbine power curve.

2.3 Wind Speed

For this scenario the wind speed will be constant throughout the farm, at 13 m/s. There will also be no wind speed variability with time of day.

2.4 Wind Direction Probability

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 in Fig. 2.

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

- θ: wind direction where north is 0°, measured clockwise.
- μ_1: first dominant wind direction (180°).
- μ_2: second dominant wind direction (350°).
- 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).

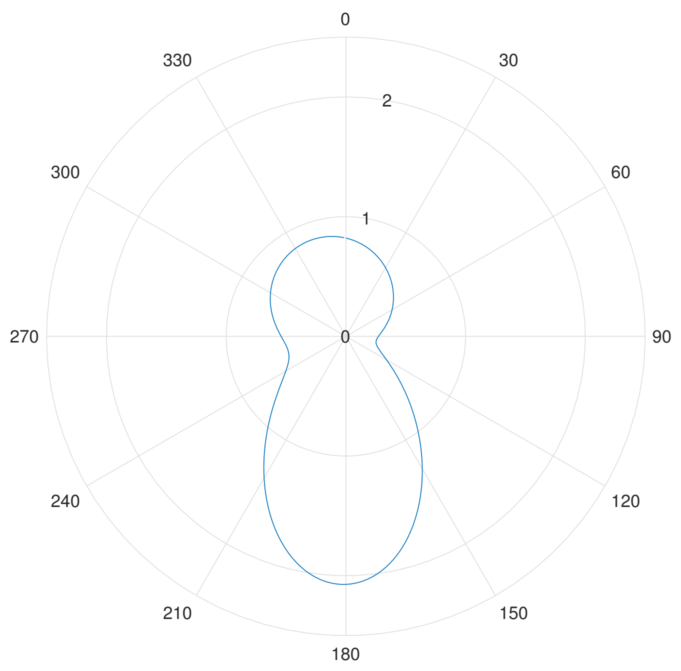

Figure 2: The wind frequency distribution; a bi-modal Gaussian distribution as defined in Eq. (2).

3 Reporting Results

3.1 Submission Contents

The following information should be included in each submission:

- Text file containing your baseline, initial, and optimal computed AEP values in Megawatt-hours, and your initial and optimal turbine locations in meters. The initial AEP and layout should be from the starting point of your submitted optimized layout. The baseline value will be used to evaluate your optimal solution, with 500 m dispersion between each turbine. The baseline value should be calculated with the following turbine locations:

16 Turbine Wind Farm		
turbine	x (m)	y (m)
0	-500	500
1	-500	0
2	-500	-500
3	-500	-1000
4	0	500
5	0	0
6	0	-500
7	0	-1000
8	500	500
9	500	0
10	500	-500
11	500	-1000
12	1000	500
13	1000	0
14	1000	-500
15	1000	-1000

36 Turbine Wind Farm		
turbine	x (m)	y (m)
0	-1000	1000
1	-1000	500
2	-1000	0
3	-1000	-500
4	-1000	-1000
5	-1000	-1500
6	-500	1000
7	-500	500
8	-500	0
9	-500	-500
10	-500	-1000
11	-500	-1500
⋮	⋮	⋮
33	1500	-500
34	1500	-1000
35	1500	-1500

64 Turbine Wind Farm		
turbine	x (m)	y (m)
0	-1500	1500
1	-1500	1000
2	-1500	500
3	-1500	0
4	-1500	-500
5	-1500	-1000
6	-1500	-1500
7	-1500	-2000
8	-500	1500
9	-500	1000
10	-500	500
11	-500	0
⋮	⋮	⋮
61	2000	-1000
62	2000	-1500
63	2000	-2000

  You **DO NOT** need to start every optimization from this layout, feel free to use random starts, intuition, warm starts, or any other method to start your optimization. Simply report the AEP at this layout from your wind farm model.

- Short description containing the relevant details of your method/process. This should include, at a minimum:
  - Wake model (including version and any modifications)
  - How the effective turbine wind speed was determined
  - 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.
    - Other relevant algorithm details
  - Your computed initial and final AEP values
  - The wind directions used during the optimization and for computing initial and final AEP values

- 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 `.txt` file with the quantitative optimization results
2. A `.pdf` of the method/process description as described in Section 3.1

The text file should contain two sections, one for the baseline, initial, and optimal AEP values and one for the turbine numbers and their corresponding 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), initial AEP (MWh), optimized AEP (MWh)
AEP_base, AEP_init, AEP_opt

# turbine num., x_init (m), y_init (m), x_opt (m), y_opt (m)
0, x0_init, y0_init, x0_opt, y0_opt
1, x1_init, y1_init, x1_opt, y1_opt
2, x2_init, y2_init, x2_opt, y2_opt
3, x3_init, y3_init, x3_opt, y3_opt
4, x4_init, y4_init, x4_opt, y4_opt
5, x5_init, y5_init, x5_opt, y5_opt
6, x6_init, y6_init, x6_opt, y6_opt
7, x7_init, y7_init, x7_opt, y7_opt
8, x8_init, y8_init, x8_opt, y8_opt
```

Figure 3: Optimization results text file example

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.