Optimized Cost-Performance Wind Farm Layout Using Genetic Algorithm

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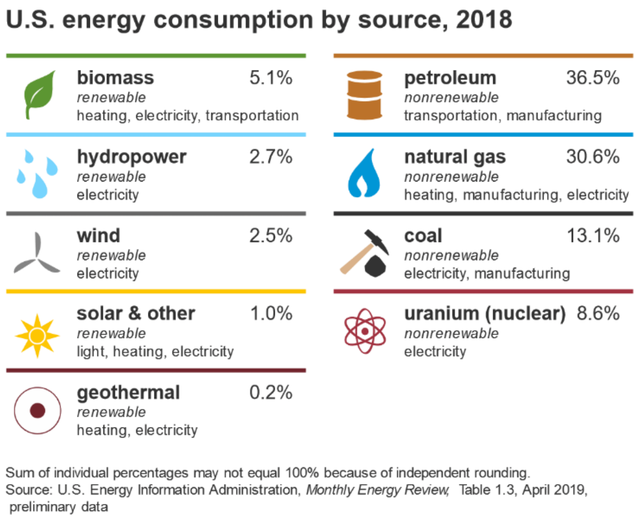
I. Introduction

As the global population continues to rise, a constant need for renewable energy increases every year. Wind Energy is one form of renewable, sustainable energy and can be made on virtually any country. However, the main problem it has is with its competition against nonrenewable resources—coal, oil, and natural gas. These three resources have a much higher cost to performance ratio as compared with many renewable resources, and therefore makes them a lower priority.

There are several ways to tackle this issue: We can artificially increase the production cost of nonrenewable resources to make them less lucrative or increase the incentive of investing in renewable resources. The goal of this research is to commit to the second solution.



To elaborate further on the benefits of wind energy as compared with other energy sources, wind turbines are relatively low-maintenance and cause very little socio-environmental disruptions—wind farms require a lot of land, but there is enough vacant space in these wind farms that other activities, such as farming, are commonly done on the same land. Birds are at risk of flying into wind turbines, but this source of death is miniscule relative to other similar constructs such as radio and cell towers, which notoriously kill significantly more animals due to electrocution. The initial cost is relatively significant, which includes many variables that will be addressed, although once placed properly, can last for several decades with minor upkeep costs. Cause for concern in terms of energy output rely on the relative position of wind turbines as well as the turbine's ability to convert kinetic energy into electrical energy. Wind Turbines that are too close in proximity in relation to the direction of the wind can cause one to lower the performance of the other.

In summary, two aspects need to be thoroughly considered when designing a wind farm: the cost of development, and the performance. Compromises will need to be made in order to achieve both—cost of development has some factors that conflict with maximizing performance, and vice-versa.

II. Methodolgy

A. *Selecting and Implementing Proper Algorithm*

Several articles have already explored this topic, but one algorithm has a constant presence: genetic algorithms. The main idea of the genetic algorithm in designing a wind farm is to assign a particular configuration a ***fitness value***, which is an arbitrary score that signifies how effective a wind farm is. Depending on a wind farm's fitness value, its layout may be considered more often or less often.

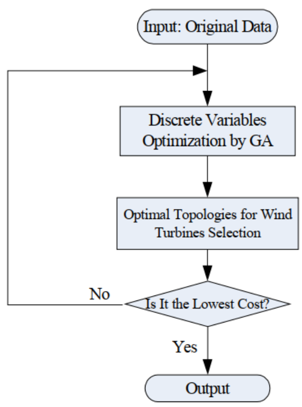


Fig.4 Flowchart of the optimization system

Source: Optimization of Electrical Connection Scheme for Large Offshore Wind Farm with Genetic Algorithm

Each generation will have a set of n randomized wind farm layouts. The best wind farm layout of that generation, as determined by its fitness value, will be displayed onto the screen and be considered much more often than the worse layouts. This is shown when designing the breeding pool. The breeding pool is an array of some size, and the representation of a wind farm in that array depends on its fitness value. For example, suppose wind farm A has a fitness value of 5, and wind farm B has a fitness value of 2. The breeding pool would look like:

Breeding Pool

A *0*	*A* *1*	*A* *2*	*A* *3*	*A* *4*	*B* *5*	*B* *6*

Length: 7

A holds 5 slots in the breeding pool while B holds 2 slots, corresponding to their fitness values.

The next generation will choose its parents on random, by selecting two slots from the above array. Thus, wind farm A has a 5/7ths chance of being a parent, whereas wind farm B has only 2/7ths chance of being a parent. This bias allows the gene pool to eventually be filled with more and more preferred wind farm layouts.

To introduce diversity, mutations occur each generation with a certain probability. For example, if ***mutation rate*** = *0.1,* then around 10% of the population will mutate into a new wind farm. The mutation that occurs is that in each of these affected wind farms, the placement of the turbines will be randomized again, and its fitness value will be recalculated. This has the effect of randomizing the fitness value, which may or may not be positive.

B. *Calculating Fitness*

The method for calculating fitness was done in considering for two aspects: cost and performance. The formulas and variables used to determine these two metrics are explained in more detail in the original articles, however a quick highlight of the variables considered are: the number of turbines (both), the cost of voltage cables (cost), the number of substations (cost), the cost of transformers at these substations (cost), the height of the wind turbines (performance), the average wind speed for a particular simulation pass (performance), the air density (performance), the roughness of the surface (performance), the efficiency of each wind turbine to convert wind kinetic energy into electrical energy (performance), the thrust coefficient (performance), the axial induction factor (performance), and the relative positions of wind turbines (both).

Consideration for each of these variables can be toggled on and off for the software.

III. Collected Results

In attempt to replicate the original research paper's findings, the default values were set to their initial conditions, and several tests were performed. Below are several results when considering only cost of development.

```
Current Generation: 100
---Best Farm of Current Generation---
Fitness Level: 1.3333322771993197
Turbine Coordinates:
[(300,100), (100,500), (500,200), (200,300), (300,300), (200,100),
(500,300), (200,200), (400,400), (400,100), (400,200), (200,500)]
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```

Attempt 1: Default Values, 100 generations

```
Current Generation: 100
---Best Farm of Current Generation---
Fitness Level: 1.3140187686684957
Turbine Coordinates:
[(300,600), (500,300), (400,500), (400,600), (300,200), (200,600),
(400,400), (500,200), (300,300), (200,300), (300,400), (400,700)]
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```

Attempt 2: Default Values, 100 generations

```
Current Generation: 100
---Best Farm of Current Generation---
Fitness Level: 1.318005748917913
Turbine Coordinates:
[(400,500), (700,400), (700,300), (800,500), (800,400), (600,400),
(400,700), (600,600), (800,300), (600,500), (400,600), (500,600)]
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```

Attempt 3: Default Values, 100 generations

The simulation results suggests that, when designing a wind farm with only initial cost in mind, the wind turbines would be placed as close together as possible, to minimize the certain parts of the initial cost, such as the number of local transformers required, and the length of voltage wires required to connect the entire system to a substation. When considering performance only, the layouts are farm less structured.

```
Current Generation: 100
---Best Farm of Current Generation---
Fitness Level: 3.815608363810816
Turbine Coordinates:
[(600,300), (0,100), (400,100), (700,500), (700,0), (200,600), (600,200),
(800,200), (200,0), (600,100), (500,0), (500,400)]
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```

Attempt 1: Default Values, 100 generations

```
Current Generation: 100
---Best Farm of Current Generation---
Fitness Level: 6.915070869457279
Turbine Coordinates:
[(200,300), (600,200), (600,300), (500,100), (700,400), (300,300), (0,100),
(300,500), (800,500), (900,100), (400,500), (700,100)]
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```

Attempt 2: Default Values, 100 generations

```
Current Generation: 100
---Best Farm of Current Generation---
Fitness Level: 8.26907633286107
Turbine Coordinates:
[(400,0), (700,100), (800,600), (200,100), (900,700), (800,0), (900,200),
(200,0), (500,200), (600,0), (700,200), (500,400)]
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```

Attempt 3: Default Values, 100 generations

The data suggests that an optimized wind farm layout considering only the performance of the wind farm will scatter the wind turbines in such a way to minimize the disturbance between the two. The simulation was done on the assumption that the wind was coming from the north, and as such the turbines are placed in each column to minimize the downstream disruption between each turbine.

Finally, considering both cost and performance fitness results in a compromise between the two:

```
Current Generation: 100
---Best Farm of Current Generation---
Fitness Level: 15.262690956508495
Turbine Coordinates:
[(900,700), (700,100), (800,500), (400,0), (500,100), (500,300), (900,300),
(300,100), (600,500), (700,400), (500,400), (700,300)]
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```

Attempt 1: Default Values, 100 generations

```
Current Generation: 100
---Best Farm of Current Generation---
Fitness Level: 15.686851788223889
Turbine Coordinates:
[(900,400), (200,0), (400,200), (600,0), (900,0), (400,0), (900,200)
(700,600), (600,400), (600,200), (900,600), (900,300)]
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```

Attempt 2: Default values, 100 generations

```
Current Generation: 100
---Best Farm of Current Generation---
Fitness Level: 11.222209734892827
Turbine Coordinates:
[(700,0), (900,200), (800,400), (500,100), (500,200), (300,0), (900,500),
(200,100), (900,600), (700,500), (900,0), (700,200)]
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```

Attempt 3: Default values, 100 generations

The wind farm layouts when considering both cost and performance cause the turbines to remain close to each other, but also stay separated to minimize interference. Abbreviations and Acronyms

IV. Conclusion

When considering certain aspects of designing a wind farm, compromises must be made. Initial cost can be minimized by reducing the net distance between each turbine/node. Performance can be maximized by reducing upstream interference between two or several wind turbines. The compromise between the two may be considered the best solution, depending on the circumstance, although considering only performance may yield the best investment output. Using the power of genetic algorithms, optimizing these wind farms can help increase the investment in wind energy, and ultimately, save our ecosystem.

H. Lingling, F. Yang and G. Xiaoming, "Optimization of electrical connection scheme for large offshore wind farm with genetic algorithm," 2009 International Conference on Sustainable Power Generation and Supply, Nanjing, 2009, pp. 1-4.

M. A. Hassoine, F. Lahlou, A. Addaim and A. A. Madi, "Wind Farm Layout Optimization using Real Coded Multi-population Genetic Algorithm," 2019 International Conference on Wireless Technologies, Embedded and Intelligent Systems (WITS), Fez, Morocco, 2019, pp. 1-5.