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Optimization of the Turbines Locating in the Wind Farm

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ABSTRACT: Nowadays, with regard to the reduction of fossil fuels and the management of their use, wind power is now rising as one of the most efficient renewable energy sources. Moreover, wind farms, which include sets of turbines in a farm, have become more developed and their designs and optimizations have risen recently. In this paper, the wind turbines are located in the wind farm and the effects of their positions and arrangements on the production power of the whole system are investigated. For this purpose, a square farm is considered and, having information on how the winds and wind speeds in each case, will extract the optimum location of turbines in the farm using optimization algorithms. The main goal of this research is to increase the total amount of power extracted from the wind farm based on the changes in the locations and arrangements of the turbines. This optimization problem is subjected to some constraints, such as the maximum number of turbines in the farm, the minimum distance between turbines and the overall size of the farm. To solve this optimization problem, the genetic algorithm and particle swarm optimization methods are used and the results of these methods are compared.

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1- Introduction

Nowadays, with increasing energy consumption in human societies, the need for energy resources has also risen. The best option for replacing fossil fuels is the use of renewable energy. Wind energy is the most efficient source of renewable energy because it has the potential to convert mechanical and electrical energies. It is also clean and does not have a damaging effect on nature. Therefore, the use of wind energy is increasing rapidly, and the number of farms and the number of turbines per farm are increasing. These features illustrate the importance of the use of turbines and extracting maximum power from these farms.

Recently, some studies have investigated the interactions of turbines on each other. The effect of turbines on wind, wind distortion and wind speed has also been studied [1-4]. Also, the optimization of wind turbine location has been carried out in different researches by examining the impact of each of the parameters [5-7].

In this work utilizing a realistic model to calculate the interference coefficient of turbines and the rate of wind speed, the intensity of wind-blown in accordance with the geography of the region (with different velocities in different directions) and the drag coefficient (as a function of the intensity of the blowing Wind) are also has been used.

2- Modeling

For modeling wind farm and studying the effects of turbines on each other, several important factors are needed:

- Calculating the rate of wind speed at the back of the first turbine and the effect on the second turbine.
- Calculate the longitudinal and transverse spacing and the angles between two turbines.
- Calculate the turbine interference density factor.
- Calculate the turbine interference coefficient.
- Calculation of objective function and constraints.

The calculation of the wind speed is dependent on the distance between the turbines. According to Fig. 1, when the distance from the front turbine is increased, the larger environment is affected, and therefore, the amount of the effect on each element of this environment is reduced.

In order to obtain the maximum output power, the value of the power generated by each turbine must be calculated. Then, the total value of the energy generated by the turbines is reduced

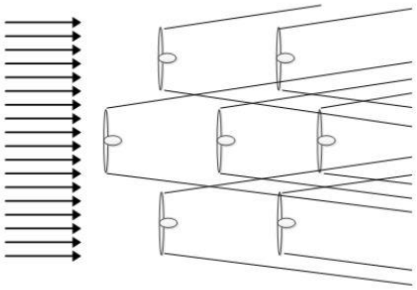

Fig. 1. Influence of the front turbine on the rear turbines

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Table 1. Turbine characteristics

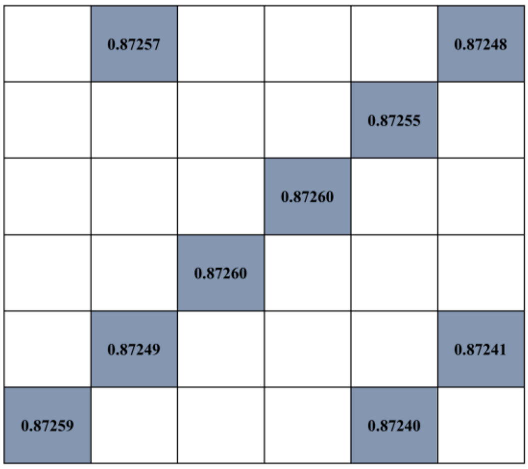
VECTOR	DIRECTION (DEGREE)	THE AMOUNT OF WIND BLOWING (٪)	SPEED (m/s)
n	15-345	8.1	7.85
NNE	15-45	21.6	9.91
ENE	45-75	15.3	7.33
E	75-105	9.4	6.23
ESE	1.5-135	2.9	4.47
SSE	135-165	1.5	3.14
S	165-195	2.1	3.74
SSW	195-225	5.7	8.24
WSW	225-255	16.9	11.74
W	255-285	9.0	8.59
WNW	285-315	4.3	4.72
NNW	315-345	3.3	5.32
all data		100	8.34

Table 2. Turbine characteristics

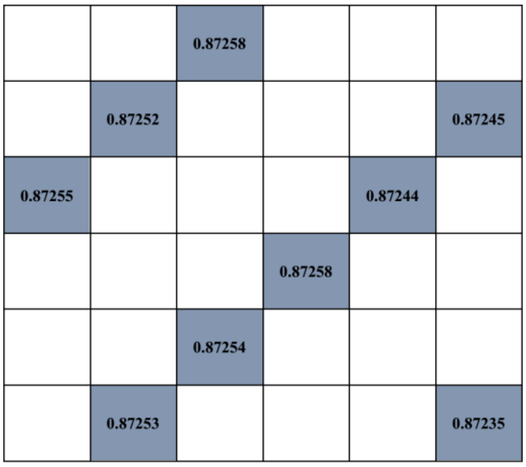
FARM DIVISIONS	NUMBER OF TURBINES	MAX POWER IN GA (MWh)	MAX POWER IN PSO (MWh)
5×5	9	7.85197	7.85197
6×6	9	7.85270	7.85255
7×7	16	13.94513	13.95005
8×8	16	13.94562	13.95194
9×9	25	21.75629	21.76839
10×10	25	21.75504	21.77380

by the interference coefficient. Finally, by summation of the amount of energy generated in each direction of the wind, the total amount of farm power is obtained. By maximizing the output power, the optimal placement of turbines is achieved with respect to the location of the turbines.

In order to calculate the objective function of the optimization problem, the farm initially divided into cells. So that for a 2×2 square-kilometer farm, the farm can be divided into 3×3, 4×4 cells and turbines can be located at the center of cells. The number of turbines in the farm will be determined from before, but the change in the arrangement of these turbines will change the extraction capacity of the farm. According to this description, the objective function of the optimization problem is obtained as follows:



a) GA

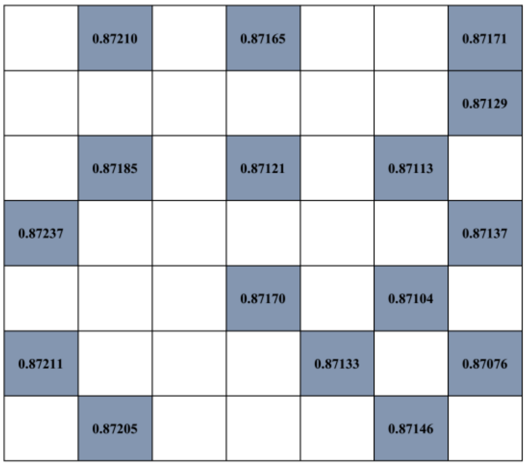


b) PSO

Fig. 2. The flow field and boundary conditions

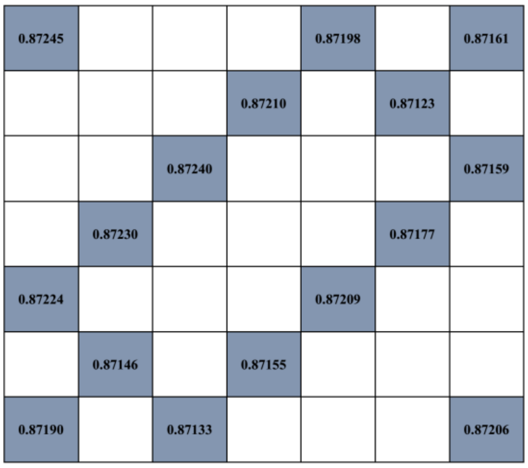
$$P_{out} = \sum_{i \in v, d \in s} w_i^d \left(P_i^d x_i - Z_i^d \right) \quad (1)$$

In this equation, P_Out is the total output of the farm, and w is the wind direction in every direction. Also, P_i^d is the total amount of power generated by each cell, which is obtained according to the Weibull function for each direction of the wind. x_i represents the turbine in the cell, so that, when turbine exists in the ith cell, the value x_i is equal to 1, and in the absence of the turbine, its value is zero. i is also a count of each cell and the location of the rear turbine, and v is the collection of cells. The variable Z_i^d is the coefficient of interference between two turbines and, in fact, it is the total reduction power in the ith turbine is due to turbines ahead. d indicates the direction of wind and s is the collection of wind directions. Given the problem form, a number of constraints are needed to obtain a logical and optimal response. Neither the number of turbines should not be more than the number of specified turbines, nor can it be more than one turbine per cell; in addition, Z_i^d must be positive. Therefore, the problem's constraints are:



	0.87210		0.87165			0.87171
						0.87129
	0.87185		0.87121		0.87113	
0.87237						0.87137
			0.87170		0.87104	
0.87211				0.87133		0.87076
	0.87205				0.87146	

a) GA



0.87245				0.87198		0.87161
			0.87210		0.87123	
		0.87240				0.87159
	0.87230				0.87177	
0.87224				0.87209		
	0.87146		0.87155			
0.87190		0.87133				0.87206

b) PSO

Fig. 3. Verification of straight-bladed turbine total moment coefficient

$$\sum_{i\in v} x_i \le b$$
$$x_i \in \{0,1\},\ z_i^d \ge 0,\ b \le v \qquad (2)$$

3- Results

To simulate the wind farm, a Vestas V80 turbine has been used, which the output power with regard to the wind speed and the thrust coefficient, can be extracted from the turbine datasheet, and using the curve fitting, the power values and the thrust coefficient are obtained. For wind values, 12 wind directions are considered, which is the most common number of wind direction, and their values are indicated by reference [8] in Table 1.

A wind farm with dimensions of 2.16 km × 2.16 km was considered and the value of tan α was also selected to be 0.075 [8]. Also, the value of r0 (the radius of the turbine blades), was set 40 m from the turbine datasheet.

The problem is solved based on the number of turbines (9, 16 and 25 turbines) and different farm divisions (5×5, 6×6, 7×7, 8×8, 9×9 and 10×10) [8]. The results of the optimization problem presented in Table 2, include the maximum amount of extracted power from the wind farm by the Genetic Algorithm (GA) and the Particle Swarm Optimization (PSO) algorithm.

With regard to the values extracted in Table 2, it can be seen that the results of the two optimization methods are very close to each other. Moreover, except in the first case (5×5) that the extraction power of the two algorithms was quite similar, and the second case (6×6) that the GA performed better, in the rest of the states or in the higher number of turbines, the PSO algorithm was reached more output power. Fig. 2 shows the location of 9 turbines in a 6×6 farm and the power of each turbine. Furthermore, Fig. 3 shows the location of 16 turbines in a 7×7 farm.

4- Conclusions

In this work, the optimal placement of the turbines in a wind farm was extracted. The solving optimization problem was used the GA and the PSO algorithms. It was based on various farm divisions (5×5, 6×6, 7×7, 8×8, 9×9 and 10×10), and the number of turbines (9, 16, and 25 turbines). Considering simultaneously some of the influential factors, including wind speed in different directions, actual turbine thrust coefficient, real turbine power output (from its catalog), and turbines interference is the innovations of this paper. By examining the results and comparing it with previous work, it can be seen that the total wind farm output has increased. Also, a general comparison shows that the neglect of the effect of the thrust coefficient has a great influence on the final output. Meanwhile, the amount of wind in each direction and wind speeds are clearly effective in locating the wind turbine, and it certainly should be used to locate the wind turbine in the wind farm. It is necessary to generate maximum power from the farm.

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