Study the Impact of Wake on the Arrangement and Economic of Variable Speed Wind Farm

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ABSTRACT

This paper focuses on arrangement and operation of variable speed wind farm. Also, it studies the wake effects on the power production from wind farm by using Jensen’s wake model. This methodology can be done by using Matlab program. The objective of every wind farm designer is producing maximum, as possible of energy, with minimal cost of installation. The optimization is done by the minimum cost per unit of energy produced. In this study an algorithm has been developed to solve the rule of thumb a wind farm layout based on the wake model of Jensen. It has the capacity to estimate the optimal number of total power produced in wind farm, in comparison with predominant wind farm. Five different wind turbine types have been used.

Keywords: Wind Turbine Model; Wind Speed; Wake Effect; Wind Farm; Matlab Program

I. INTRODUCTION

If a wind turbine, WT, is working within the region of the wake of another turbine, or at a point within the wind farm, WF, which is affected by several of these wakes, then the turbine will produce less energy than those turbines that interact directly with the natural wind flow. Therefore the layout of wind farms is very important, since it has impact in the economic, safety and reliability evaluations of the system.

II. TURBINE PLACEMENT

Turbines typically are placed in rows perpendicular to the prevailing wind direction. Two turbine spacing has been defined as follows:

- $D_{cw}$ is the cross wind spacing within a row of turbines. It's range taken from two to four times of rotor diameters, $D$. $D_{cw}$ is the downwind spacing between rows of turbines. It is range taken from five to ten times of $D$. [1, 2]

A. Determine Suitable Type, Number and placement of WT.

The main goal is to determine the optimal wind turbines type, number and placement to get maximal power output while minimizing the investment costs and considering different practical requirements and restrictions.

In this paper the comparative study will be done between two cases, the first case is predominant wind farm module and the second case is the thumb wind farm module as shown in Fig. 1 [3]. The downwind spacing $D_{ow}$ is varying from 5 rotor diameters to 10.5 rotor diameters in rows and the cross wind $D_{cw}$ is 3 rotor diameters Coolum apart for two cases.
The number of wind turbines in a row \( N_{row} \), and number of wind turbines in a column \( N_{col} \) can be determined for given area with length \( D_{row} \) and \( D_{col} \) taking into consideration the separation distances between turbines \( D_{dc} \) and \( D_{cw} \) as in ref. [1]:

\[
N_{row} = \frac{D_{row}}{D_{dc} + 1}
\]

Then \( N_{col} \) can be determined as:[1]

\[
N_{col} = \frac{D_{col}}{D_{cw} + 1}
\]

Also, the total number of turbines \( N \), can be estimated as:[1]

\[
N = N_{row} \times N_{col}
\]

B. Wake Effects and the Cost Model

To estimate the power produced from a wind turbine operating in the wake of one or more wind turbines, an analytical wake model developed by Jensen [3, 4, 5 and 6] is chosen.

It is based on global momentum conservation in the wake downstream of the wind turbine as shown in Fig. 2. The wake effect can be determined from Equation (4) [4, 5 and 7]

\[
u_j = u_o(1 - u_{df}(j))
\]

Where;

\( u_j \) The wind set of turbines affecting position \( j \) with a wake.

\( u_{df}(j) \) The wind affecting position \( j \) with a wake.

To determine the cost of the wind farm, a cost model is selected. The model chosen was also used in previous studies [7]. The total cost per year for the entire wind farm can be expressed as: [7]

\[
Cost = N \left[ \frac{2}{3} + \frac{1}{3} e^{-0.00179N^2} \right]
\]

(5)

The objective function that will lead to optimization (minimum cost per unit of energy produced) is expressed as:

\[
Objective\ function = \frac{Cost}{P_{e,ave}}
\]

(6)

Where;

\( P_{e,ave} \) Average power of wind turbine. It has been taken from ref. [8]

III. RESULTS

In this study, the use of five types of wind turbines and the hourly wind speed for the selected site is the first data required for design of wind farm. The data has been obtained from the Egyptian Metrological Authority for Gable Elzait site at Gulf of Suez, Egypt [8]. Figure 3 shows the hourly wind speed over the year.
The distributions of wind turbines in wind farm design have strong impact on the wind speed and also the power generated from wind farm. The distributions of WT by using the thump method is less effect on wind speed than the distributions of WT by using the predominant method, as shown in Fig. 4.

Effect of distance between turbine on yearly energy production for predominant wind farm and thump wind farm is shown in Fig. 5. Figure 6 shows wind speed with wake effect on wind farm: (a) wind speed at row1 (b) wind speed at row2 (c) wind speed at row3: (d) wind speed at row4.

The cost and objective function has been calculated according to equations (5 and 6). Figure 7 and Fig. 8 show the effect of distance between turbine on cost per unit energy and objective function respectively. Wind turbine distribution effect on the maximum power that produced from WT, shown in Fig. 9.

### TABLE 1

**Characteristics of the Selected WTG’s**

<table>
<thead>
<tr>
<th>Character</th>
<th>Type</th>
<th>RPM</th>
<th>P</th>
<th>Wm/s</th>
<th>Uc</th>
<th>Uf</th>
<th>H</th>
<th>D</th>
<th>A w, m²</th>
<th>Operation interval rpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE 1.6</td>
<td>1, 6</td>
<td>3.5</td>
<td>11</td>
<td>25</td>
<td>9</td>
<td>6</td>
<td>100</td>
<td>7.8</td>
<td>10³</td>
<td>9.75-16.2</td>
</tr>
<tr>
<td>SWT 4</td>
<td>4, 5</td>
<td>11</td>
<td>25</td>
<td>8</td>
<td>9</td>
<td>5</td>
<td>130</td>
<td>13.3</td>
<td>5-13</td>
<td></td>
</tr>
<tr>
<td>FD77</td>
<td>1, 5</td>
<td>3</td>
<td>11</td>
<td>21</td>
<td>7</td>
<td>4</td>
<td>77</td>
<td>4.6</td>
<td>10³</td>
<td>11.1-18.1</td>
</tr>
<tr>
<td>Repower</td>
<td>6, 1</td>
<td>3.5</td>
<td>14</td>
<td>30</td>
<td>9</td>
<td>5</td>
<td>126</td>
<td>12.46</td>
<td>9</td>
<td>7.7-12.1</td>
</tr>
<tr>
<td>CT3000</td>
<td>3</td>
<td>3.5</td>
<td>11</td>
<td>25</td>
<td>9</td>
<td>0</td>
<td>103</td>
<td>8.4</td>
<td>10³</td>
<td>8.34-15.73</td>
</tr>
</tbody>
</table>

![Figure 3: The hourly wind speed over the year.](image)

![Figure 4: Effect of distance between turbines on Percentage wind wake (wind speed).](image)

![Figure 5: Effect distance between turbines on yearly energy production for predominant wind farm and thump wind farm.](image)
Figure 6: Wind speed with wake effect of wind farm: (a) wind speed at row1 (b) wind speed at row2 (c) wind speed at row3: (d) wind speed at row4

Figure 7: Effect distance between turbines on cost per unit energy

Figure 8: Effect distance between turbine on objective function.

Figure 9: Impact the distribution of WT on Power generated from WF by using thump method.

In the case of the thumb wind farm module the Repower wind turbine produces yearly energy more than other turbines. This can be shown as in Table (2). From this table it can be seen that:

1. The Repower wind turbine produces yearly energy more than the GE wind turbine with 46.71 % w. r. to the output of Repower wind turbine and less cost objective function.

2. The Repower wind turbine produces yearly energy more than the SWT wind turbine with 28.58 % w. r. to the output of Repower wind turbine and less cost objective function. But the cost for SWT is less than the cost of Repower wind turbine with 5%.

3. The Repower wind turbine produces yearly energy more than the FD wind turbine with 43.5 % w. r. to the output of Repower wind turbine and less cost objective function.

4. The Repower wind turbine produces yearly energy more than the CT wind turbine with 27.16 % w. r. to the output of Repower wind turbine and less cost objective function.

<table>
<thead>
<tr>
<th>Type of Turbine</th>
<th>Distance between turbines (m)</th>
<th>Nrow</th>
<th>Ncol</th>
<th>N</th>
<th>Yearly Energy Production (MWh)</th>
<th>Cost per unit of energy</th>
<th>Objective Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE</td>
<td>8.5</td>
<td>5</td>
<td>21</td>
<td>10</td>
<td>1.1951*1</td>
<td>70</td>
<td>5.86</td>
</tr>
</tbody>
</table>
In the case of the predominated wind farm module the Repower wind turbine produces yearly energy more than other turbines. This can be shown as in Table (3). From this table it can be seen that:-

1. The Repower wind turbine produces yearly energy more than the GE wind turbine with 45.76 % w. r. to the output of Repower wind turbine and less cost objective function.

2. The Repower wind turbine produces yearly energy more than the SWT wind turbine with 22.25 % w. r. to the output of Repower wind turbine and less cost objective function. But the cost for SWT is less than the cost of Repower wind turbine with 5%.

3. The Repower wind turbine produces yearly energy more than the FD wind turbine with 45.55 % w. r. to the output of Repower wind turbine and less cost objective function.

4. The Repower wind turbine produces yearly energy more than the CT wind turbine with 28.06 % w. r. to the output of Repower wind turbine and less cost objective function.

### V. REFERENCES


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