© 2018 IJSRSET | Volume 4 | Issue 4 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section : Engineering and Technology

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

Hassan H. El-Tamaly[1], Ayman Yousef Nassef[2]

[1]Professor of Electrical Power Engineering, Faculty of Engineering, Minia University, Elminia, Egypt
[2]Engineer in Middle Egypt Company for Electricity Distribution, Elminia, Egypt

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_{dw} 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_{dw} 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.

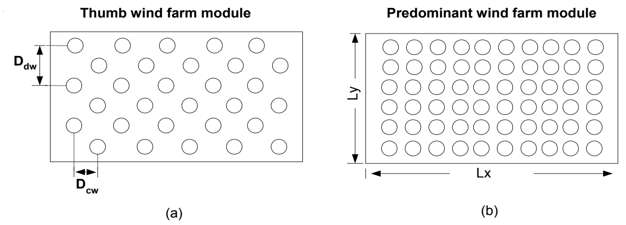

Figure 1 : Wind turbines sample placement for: (a) thumb wind farm module (b) for predominant wind farm module.

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_{dw} and D_{cw} as in ref. [1]:

$$N_{row} = \frac{D_{row}}{D_{dw}} + 1 \quad (1)$$

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

$$N_{col} = \frac{D_{col}}{D_{cw}} + 1 \quad (2)$$

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

$$N = N_{row} N_{col}$$

(3)

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]

$$u_j = u_o\left(1 - u_{def}(j)\right)$$

(4)

Where;

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

$u_{def}(j)$ The wind affecting position j with a wake

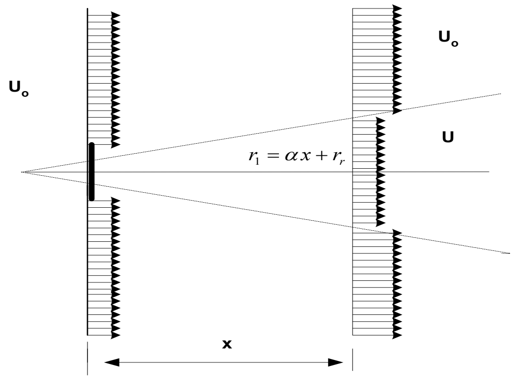

Figure 2: Wake from a single wind turbine

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]

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

(5)

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

$$Objective\ function = \frac{Cost}{P_{e,ave}} \quad (6)$$

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.

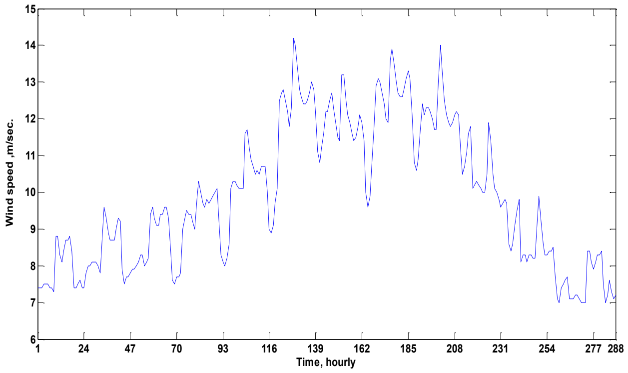

Figure 3 : The hourly wind speed over the year.

MATLAB software has been used to design the program to find the most suitable setting for the turbines to the maximum power. To determine a situation of turbines ratios and optimum number of wind turbines the distance between each column has been taken to be 3 D and the distance between the rows has been changed from 5 D to 10.5 D. Table (1) shows the wind turbine characteristics.

TABLE 1

CHARACTERISTICS OF THE SELECTED WTG'S

Charact / Type	P R MW	Uc m/s	Ur m/s	Uf m/s	H m	D m	Aw, m^2 $*10^3$	Operation interval rpm
GE 1.6	1.6	3.5	11	25	96	100	7.854	9.75-16.2
SWT 4	4	5	11	25	89.5	130	13.3	5-13
FD77	1.5	3	11.5	21	74	77	4.657	11.1-18.1
Repower	6.15	3.5	14	30	95	126	12.469	7.7-12.1
CT3000	3	3.5	11.7	25	90	103.94	8.48	8.34-15.73

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.

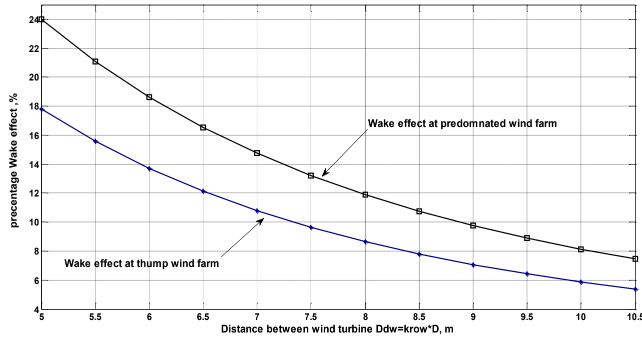

Figure 4: Effect of distance between turbines on Percentage wind wake (wind speed).

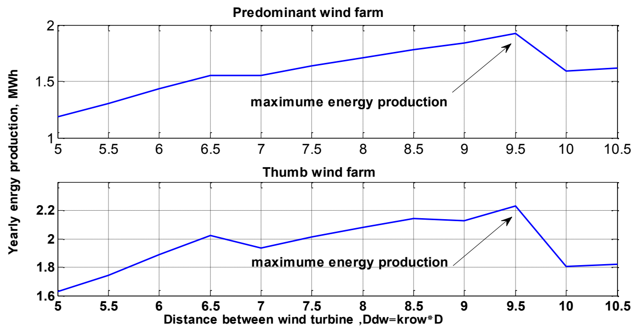

Figure 5: Effect distance between turbines on yearly energy production for predominant wind farm and thump wind farm

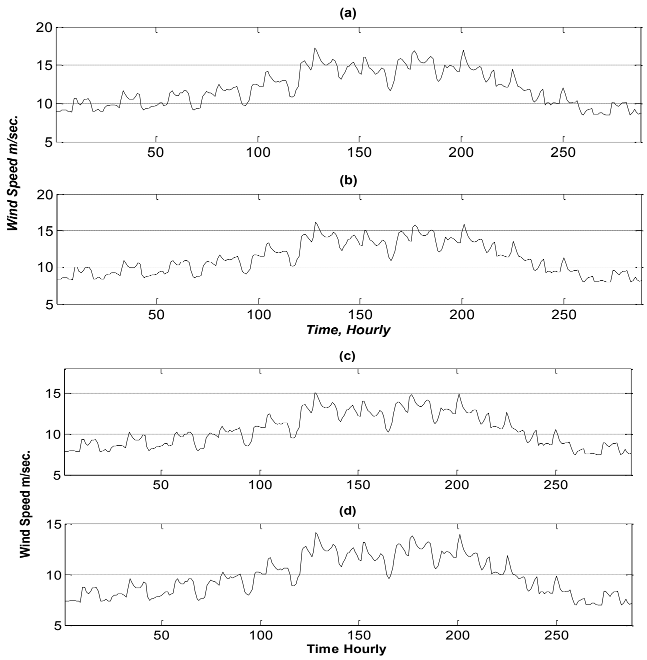

Figure 6: Wind speed with wake effect of wind farm: (a) wind speed at row1 (b) wind speed at row2 (c) wind speed at row3: (d) wind speed at row4

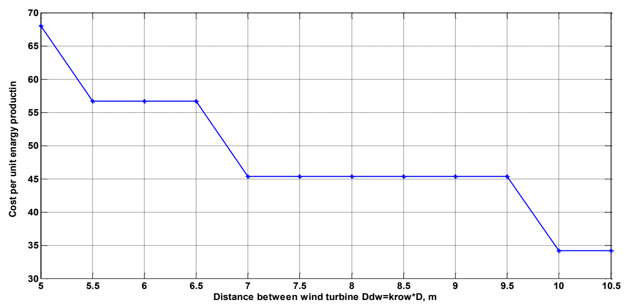

Figure 7: Effect distance between turbines on cost per unit energy

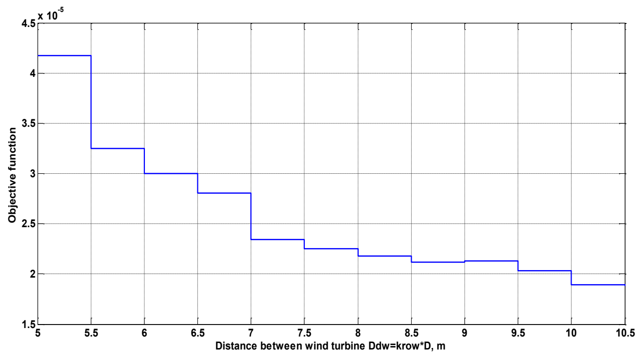

Figure 8 : Effect distance between turbine on objective function.

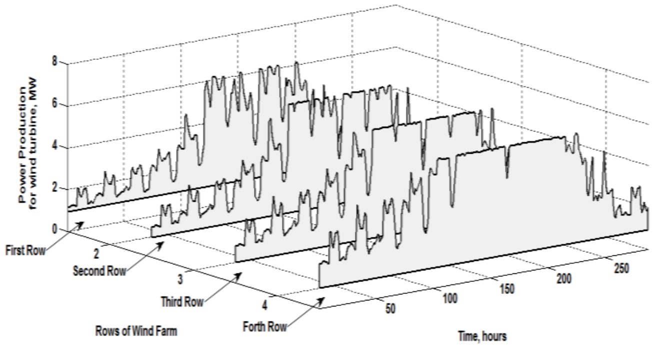

Figure 9: Impact the distribution of WT on Power generated from WF by using thump method.

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 2

DESIGN PARAMETERS OF THE THUMB WIND FARM USING DIFFERENT SELECTED WIND TURBINES.

Type of Turbine	Distance between turbine m	N_{row}	N_{col}	N	Yearly Energy Production MWh	cost per unit of energy	Objective Function
GE	8.5D	5	21	10	1.1951*1	70	5.86*

1.6-100				5	0^{6}		10^{-5}
SWT 4-130	9D	4	16	64	$1.6015*10^{6}$	42.6	$2.67*10^{-5}$
FD77-1500	8.5D	6	27	162	$1.2670*10^{6}$	108	$8.52*10^{-5}$
6M - repower	9.5D	4	17	68	$2.2425*10^{6}$	45.3	$2.02*10^{-5}$
C T 3000	8D	5	20	100	$1.6335*10^{6}$	66.6	$4.08*10^{-5}$

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.

TABLE 3

DESIGN PARAMETERS OF THE PREDOMINANT WIND FARM USING DIFFERENT SELECTED WIND TURBINES.

Type of Turbine	Distance between turbine m	N_{row}	N_{col}	N	Yearly Energy Production MWh	cost per unit of energy	Objective Function
GE 1.6-100	8.5D	5	21	105	$1.0504*10^{6}$	70	$6.66*10^{-5}$
SWT 4-130	9D	4	16	64	$1.5058*10^{6}$	42.6	$2.85*10^{-5}$
FD77-1500	8.5D	6	27	162	$1.0545*10^{6}$	108	$10.21*10^{-5}$
6M - repower	9.5D	4	17	68	$1.9367*10^{6}$	45.3	$2.34*10^{-5}$
C T 3000	8D	5	20	100	$1.3932*10^{6}$	66.6	$4.79*10^{-5}$

IV. CONCLUSION

From the study results described above it can be concluded that the power output in the case of the thumb is greater than that the power output in the case of predominant for each turbine under study as follows:

Use GE wind turbine increases energy production with the rate of 12.11%. Use SWT wind turbine increases energy, production with the rate of 5.98%. Use FD wind turbine increases energy production with the rate of 16.77%. Use Repower wind turbine increases energy production with the rate of 13.64%. Use CT wind turbine increases energy production with the rate of 14.71%. So, the thumbs wind farm module is appropriate in the design of the high productive capacity and low cost for the rest of the roads.

V. REFERENCES

[1] Handbook Dr. Gary L. Johnson "Wind Energy Systems", electronic edition October 10, 2006

[2] S. Heier, Grid integration of wind energy conversion systems, JohnWiley & Sons Ltd, Chichester, 1998

[3] Brendan Fox, Leslie Bryans, Damian Flynn, Nick Jenkins, David Milborrow, Mark O'Malley, Richard Watson and Olimpo Anaya-Lara "Wind Power Integration Connection and System Operational Aspects"@ The Institution

of Engineering and Technology Book Second Edition 2014

[4] Michele Samorani, P. M. Pardalos et al. (eds.), Handbook of Wind Power Systems, Energy Systems, DOI: 10.1007/978-3-642-41080-2_2, _ Springer-Verlag Berlin Heidelberg 2013.

[5]] Jensen NO, 1983. A note on Wind Generator Interaction. Riso National aboratory,Roskilde, mark

[6] Marmidis G, Lazarou S, Pyrgioti E. Optimal placement of wind turbines in a wind park using Monte Carlo simulation. Renewable Energy 2008;33: 1455–60

[7] Sisbot S, Turgut Ö, Tunç M et al (2010). Optimal positioning of wind turbines on Gökçeada using multi-objective genetic algorithm. Wind Energy 13:297–306

[8] Hassan H. El-Tamaly, Ayman Yousef Nassef. "Tip speed ratio and Pitch angle control based on ANN for putting variable speed WTG on MPP", 2016 Eighteenth International Middle East Power Systems Conference (MEPCON), 2016

[9] "College of Engineering: Wind Turbines", 21 June 2010 [Online]. Available: http://people.bu.edu/dew11/windturbin e.html. [Accessed 10 March 2014].