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Comparison of different wind farm layouts for a 25 MW project in the south west of Algeria

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Abstract. The object of this work is to evaluate and compute the power potential of the KABERTEN site and to make the rigorous choice among different placements of wind turbines in order to decrease the wake effect and improve the power efficiency. Three proposals of wind farm layouts where all the turbines are faced to the prevailing wind have been used in the simulations. The results for individual and global energy yield as well as wake loss have been obtained and plotted. The wind Atlas Application Program (WASP) software of the Danish RISO laboratory is used in the study as a simulation tool to evaluate potential of the chosen site and to determine the best wind farm layout for a 25 MW project.

Keywords

Wind energy Potential, wind farm layout, wake effect, turbines placement, WASP

1. Introduction

In order to make your wind energy project economically viable wind turbine placement is one of the most important factors to consider. The good selection of location for your wind turbine can in many cases mean the difference between economic success and failure to even return the investment. The location needs to have constantly high wind speeds to ensure the maximum efficiency but factors like the availability of transmission lines, value of energy to be produced, cost of land acquisition, land use considerations, and the environmental impact should also be considered. Many attempts have been made in optimizing wind turbines positioning. As rule of thumb, 10 ha/MW can be taken as the land requirement of wind farms, including infrastructure. The spacing of a cluster of machines in a wind farm depends on the morphology of the terrain, the wind direction and speed, and the turbine size. The optimal spacing is found in rows 8–12 rotor diameters apart in the windward direction, and 1.5–3 rotor diameters apart in the crosswind direction [1]-[2]. If the wind strikes a second turbine before the wind speed has been restored from striking an earlier turbine, the energy production from the second turbine will be decreased relative to the unshielded one. The amount of decrease is a function of the wind shear, the turbulence in the wind, the turbulence added by the turbines and the terrain. Spacing the turbines further apart will produce more power but at the expense of more land more roads and more electrical wire. The wind leaving the turbine must have lower energy content than the wind arriving in front of the turbine. A wind turbine will always cast a wind shade in the downwind direction. In fact, there will be a wake behind the turbine, i.e. a long trail of wind which is quite turbulent and slowed down, when compared to the wind arriving in front of the turbine. When choosing the perfect placement for wind turbine many wind farm designers use specialized wind energy software applications to determine the efficiency and economic benefits of given wind energy project. In our study the WASP software has been used to evaluate potential of the chosen site and to determine the best wind farm layout for a 25 MW project to be installed in the south west of Algeria precisely at KABERTENE in the province of ADRAR which is the windiest part of the country [3]-[4]. Three proposals of wind farm layouts where all the turbines are faced to the prevailing wind have been used in the simulations. The geological and meteorological data used in the simulation were given by the *National Office of Meteorology* (ONM).

2. Wind Potential of Algeria

Algeria has a moderate wind speed (2 to 6.5 m/s). It is noted that the South is characterized by higher wind speeds than the North, more particularly the Southwest, with average speeds higher than 6 m/s, especially in the ADRAR region with wind speed peaks up to 20 m/s [3]. Concerning the North, one globally notices that average speed is not very high. However, the wind speed varies also in function of the seasons and the windiest season is spring. Winter and autumn are less windy than the other seasons [3]. The wind chart indicating the yearly average wind speeds measured at 10 m height is given in Fig. 1 [5].

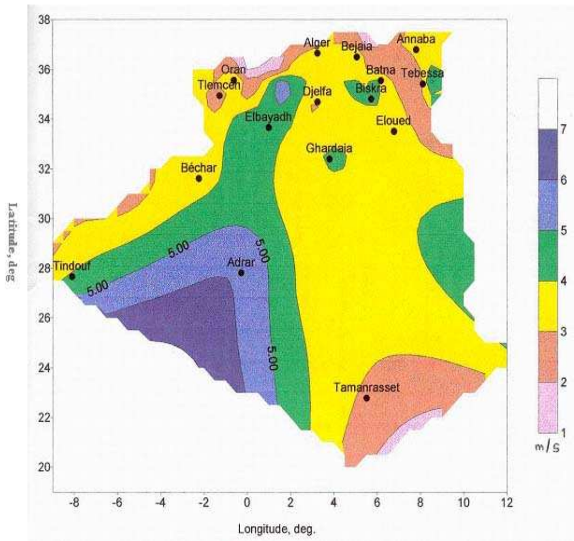

Fig. 1. Wind Chart of Algeria [5]

A. KABERTENE site Potential evaluation

With an altitude of 260 m, the site whose photos are given in Appendix is ideal for wind farm implementation because:

- It is located at 72 km from the town (ADRAR) and near the main road which reduces project transportation difficulties and costs.
- It is neighbor to a 30/220kV power transmission station. The connection to the grid is easier and cheaper.
- The availability of space, a smooth topography and a weak soil roughness. More freedom for the project installation.

Using WASP and the measured (at 50 m height from ground) meteorological data of the ADRAR region between 2003 and 2008, the following characteristics were determined: Wind average speed, WEIBULL distribution shown in Fig.2, wind Rose given in Fig.3 as well as the Power density. Using a scanned copy of the topographic card of the region of ADRAR (scale 1/500 000) given by the national institute of cartography and topography (INCT), the map editor of WASP has been employed and 3 points were taken to geo- reference the card and digitalize the lines of the level. A defined class of roughness has been assigned for each zone. The roughness is a characteristic of the ground cover which influences the wind intensity. With the relief these data have been formatted then injected as input data to the software in order to compute the potential. They constitute a MAP file that models the site. Wind measurements are used to define the annual average statistics put in TAB file. Then the WASP computes the wind Atlas that allows the determination of the wind characteristics at different heights and roughness classes [6]-[7].

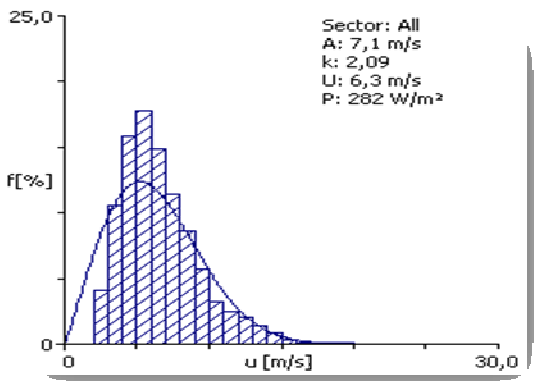

Fig. 2. Wind Speeds distribution (2003-2008) [6]

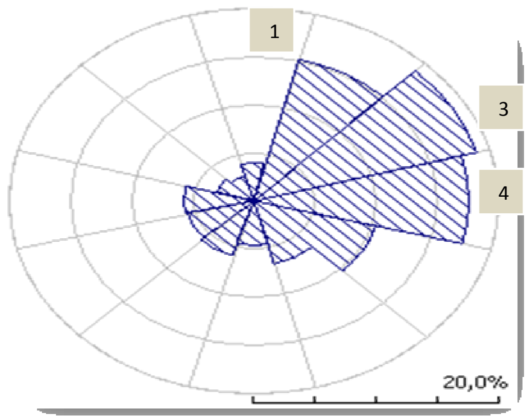

Fig. 3. Wind Rose (2003-2008) [6]

More than 18 % of the year time the wind speed is around 6 m/s as shown in Fig.2. One can notice from Fig. 3 that the wind is prevailing in sectors 2, 3, 4 and 5. At 50m height the measured data has given the following wind speeds distribution.

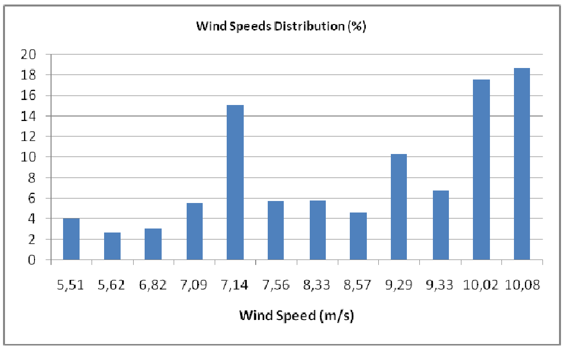

Fig. 4. Site Wind speed distribution (50m height)

3. Three vs. Two blades Wind Turbines

A two blades 1 MW wind turbine GEV HP of the French manufacturer VERGNET is used in the simulation and the data are given in Appendix. Two bladed or three bladed wind turbines are usually used for electricity power generation. Turbines with 20 or more blades are used for mechanical water pumping. The number of rotor blades is indirectly linked to the tip speed ratio. Wind turbines with high number of blades have a low tip speed ratio but a high starting torque. Wind turbines with 2 or 3 blades have a high tip speed ratio but only a low starting torque. These turbines might need to be started if the wind speed reaches the operation range. A high tip speed ratio, however, allows the use of smaller and therefore lighter gearbox to achieve the required high speed at the driving shaft of the power generator. Currently three bladed wind turbines dominate the market for the grid connected horizontal axis wind turbines. They have the advantage that the rotor moment of inertia is easier to understand and therefore often better to handle than the moment of inertia of a two bladed wind turbine. Furthermore, they are often attributed ‘better’ visual aesthetics and a lower noise level than the two bladed ones. Both aspects are important considerations for wind turbines applications in highly populated areas. Two bladed wind turbines have in contrast the advantage that the tower top weight is lighter and therefore the whole supporting structure can be built lighter and the related costs are very likely to be lower [8].

4. Simulation

For choosing the best wind farm layout in terms of energy yield and wake effect loss, three configurations of wind turbine placement have been used in the simulation.

A. First Wind Farm Configuration

The placement of the turbines is random and the total surface of the KABERTENE site is occupied as shown in Fig.5. The wake effect loss is 0.61 % according to Table I. The detailed results for each wind turbine are given in Fig.6. The wake loss for the first turbine is null. This is due to its good position and absence of wake effect influence of the neighboring turbines. It is a bit higher for turbine 19 (see Fig.5) due to the influence of the surrounding turbines. Although this configuration has the smallest wake loss, it has however many drawbacks like the fact that the majority of the turbines are affected by the wake and they occupy the totality of the site area. Hence problem of connection thus high wirings cost.

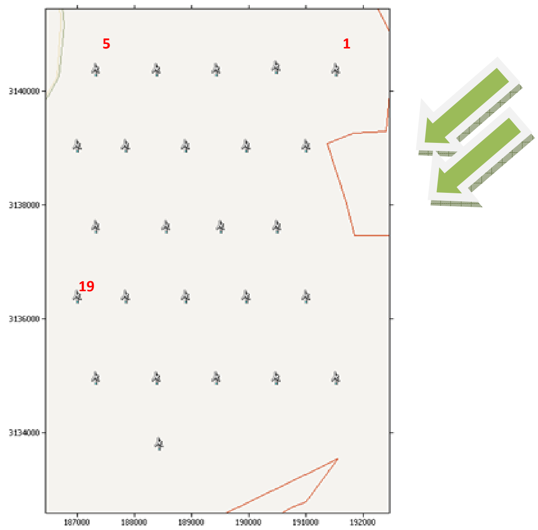

Fig. 5. First Wind Farm layout

Table I. - Total gross and net annual energy production (in GWh)

Variable	Total	Mean	Min	Max
Gross AEP	81,015	3,241	3,095	3,296
Net AEP	80,518	3,221	3,069	3,274
Wake loss [%]	0,61	-	-	-

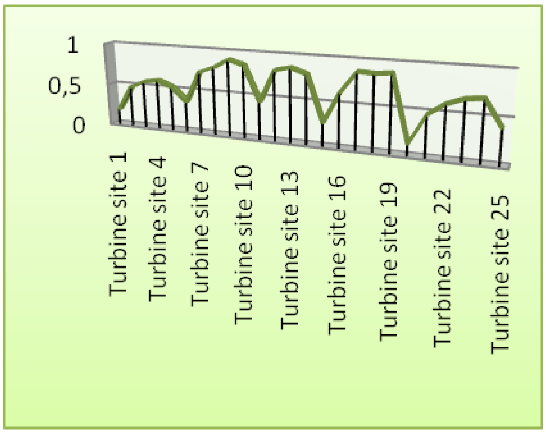

Fig. 6. Wake loss Variation for each turbine

B. Second Wind Farm Configuration

The turbines were placed in one row facing to the prevailing winds as shown in Fig.7. The wake loss is 1.31% as indicated in Table II. The plots of the results in detail for each wind turbine are given in Fig.8. Peaks of wake loss are reached with turbines 15, 17 and 19. Except turbines 1 and 25 the others have the same loss.

Table II. - Total gross and net annual energy production (in GWh)

Variable	Total	Mean	Min	Max
Gross AEP	81,213	3,249	3,139	3,292
Net AEP	80,149	3,206	3,104	3,267
Wake loss [%]	1,31	-	-	-

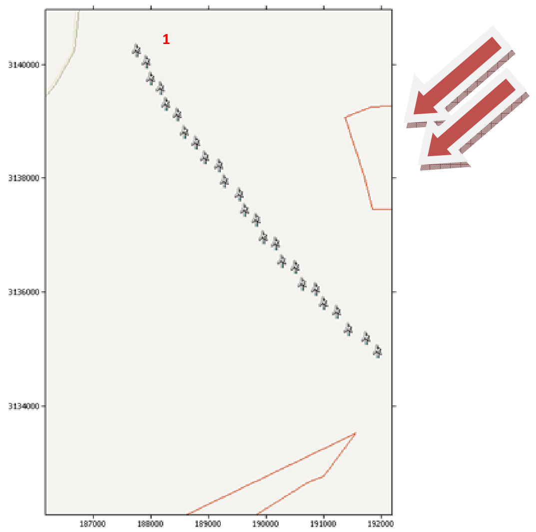

Fig. 7. Second Wind Farm layout

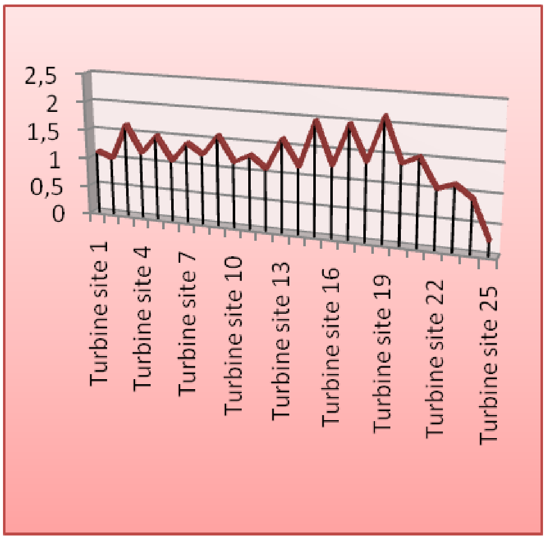

Fig. 8. Wake loss Variation for each turbine

C. Third Wind Farm Configuration

Two rows of wind turbines have been placed facing to the prevailing winds as shown in Fig.9. A minimal distance between two turbines of the same row is 4 D (D: rotor diameter) and between two turbines of different rows of 8D. The computed total annual energy production in GWh and the wake effect loss in percent are given in Table 3 and plotted for each turbine in Fig.4.

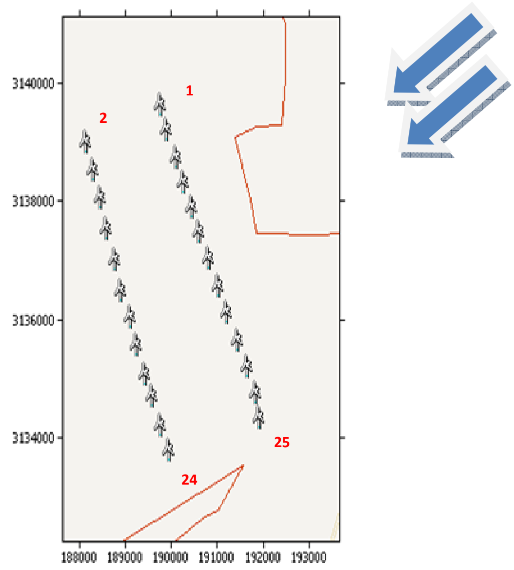

Fig. 9. Third Wind Farm layout

The wake effect loss is very small (0.78%) as shown in Table III. The plots of the results in detail for each wind turbine are given in Fig.10. The best energy efficiency is obtained in this simulation. Even though this value can be improved but with the expense of land and connection to network costs.

Table III. - Total gross and net annual energy production (in GWh)

Variable	Total	Mean	Min	Max
Gross AEP	82,723	3,309	3,243	3,349
Net AEP	82,075	3,283	3,208	3,329
Wake loss [%]	0,78	-	-	-

This configuration has the highest Annual Energy production and a good efficiency. Turbines 16 to 23 have a higher loss because they are the most disturbed by the wake effect caused by the turbines of the first row as shown in Fig.10.

5. Conclusion

The simulation of three typical wind farm layouts using WASP software had led to :

- Quantify the gross and net annual energy that could be produced by the wind farm at different wind conditions.
- Find the wake loss for different turbine placements.
- Determine the best wind farm layout for the futur site of KABERTENE in terms of turbines power production efficiency.

The results obtained proved that the third configuration is the best one for this site because the rules of turbines placement were considered.

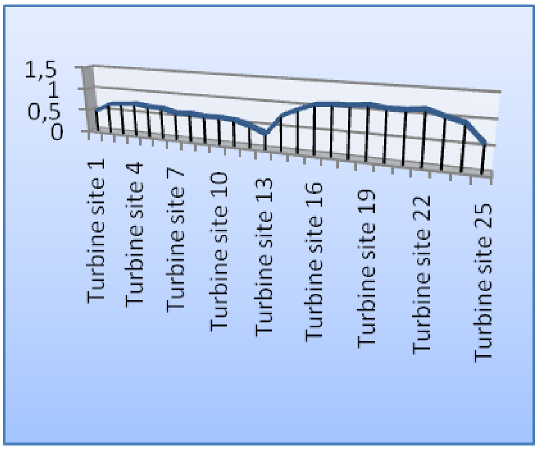

Fig. 10. Wake loss Variation for each turbine

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Appendix: Wind Turbine data

Diameter (m)	62
Nominal Power (kW)	1 000
Height (m)	70
Cut-in Speed (m /s)	3
Cut-off Speed (m/s)	25
Wind Nominal speed (m/s)	15
Delivered voltage and frequency	690 V-50 or 60 Hz
IEC 61400-1 Class	III, A (turbulence)
Swept Area (m²)	3 019
Maximum Power Coefficient Cp	0,43
Generator	Squirrel cage IM

(East side)

(South side)

(West side: 30/220kV power station)

Fig. 11. Photos of the site [6]