COMPUTATIONAL FLUID DYNAMIC ANALYSES OF WIND TURBINES FOR SOKE REGION

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***Abstract:** Wind turbines are very important electro-mechanical devices converting the wind's kinetic energy into electrical energy. Due to poor configurations in design and layout of wind turbines, energy cannot be harvested efficiently. Therefore, this study focused on the optimization of four different configurations using Computational Fluid Dynamics (CFD). The solid state models of the wind turbines were created and all components were assembled using Autodesk Inventor. Four different configurations such as in-line, side-by-side, triangular and diagonal were conceptually planned and implemented in simulations. The weather data for Soke Region were obtained. These data were used as an input to CFD calculations. CFD computations were conducted by Fluent Analysis Software in Ansys in order to find the best pattern. These configurations were tested using wind speed values obtained from the weather data. Furthermore, the calculation performance of CFD with a rectangular enclosure type was investigated. The obtained results showed that diagonal and triangular patterns had better harvesting capacity than the others*
***Key words:** Coal Mine Conveyor, Discrete Element Method, Finite Element Analysis, Granular Material.*

1. INTRODUCTION

Renewable energy is the energy that can be obtained permanently from the natural sources energy flow and which can be used continuously. Wind is generated from the temperature and the pressure difference due to the solar energy. Wind is the relative movement of the air stream displaced from the high pressure area to the low pressure area with respect to the earth surface. Wind energy is given to the kinetic energy obtained from the motion of the air stream. Kinetic energy of wind converts from mechanical energy and that mechanical energy is converted into electrical energy [1]. Wind turbine components consist of tower, blades, rotor, gearbox, generator and electrical-electronics components [2].

The wind farm is formed by placing many wind turbines in a determined area. Wind turbine locations are determined to form the most efficient wind farm. Wind farm layout optimization aim is maximizing the total produced power of wind farm. Wake models were investigated and compared different wake models for wind farm layout optimization. As a result, Jensen's model was to determine effective wake model for wind farm layout [3]. Evaluative algorithm to work on optimization of wind farm turbines layout [4]. New mathematical programming approach were determined to optimize wind farm layouts [5]. Sequential convex programming was studied for layout optimization for maximizing wind farm power production. The optimized wind farm layout augmented the wind farm power efficiency by 7.3%. [6]. Optimization layout wind farm under uncertainty for different types of layout were created [7]. Multi-population genetic algorithm for wind turbine layout optimization were established [8]. Particle filtering approach was developed by optimizing the layout model of the problem with three different cases of the wind speed and its direction distribution of the windy site. which particle filtering approach [9]. Genetic algorithm for optimization of wind farm layout was studied [10]. In order to increase high power wind harvesting a model for wind turbine

placement based on the wind distribution to maximize the wind energy capture was explored [11]. First constraint programming (CP) and mixed integer linear programming (MIP) models were developed for wind farm layout optimization [12].

In this study, four types of wind turbine layout were determined for wind farm with considering the parameters that affected the wind turbine efficiency. An optimization process was conducted to gain better results for wind farm layout by considering the parameters; time, layout effectiveness, generated electricity energy effectivity.

2. MATERIAL AND METHOD

2.1. Material

In order to determine the ideal materials for wind turbine, it should be taken account into some criteria's. They are low density and weight to decrease the gravitational forces, high strength to meet strong wind loading, high fatigue resistance to endure cyclic load and high lightning resistance, etc. A detailed study on the Structural Analysis of composite wind turbine blade by using Glass-Epoxy as a material was carried out by researchers recently [13]. Glass-Epoxy is lightweight and strong enough; therefore, this material was selected for this case study.

2.2. Method

A computerized fluid simulation study was constructed and run in ANSYS Fluent Computational Fluid Dynamics (CFD) simulator with Fluid Flow (Fluent) to gain a better understanding of wind farm flows. Figure 1 represents the flowchart of processing and simulation in the ANSYS Workbench.

2.3. Design of Layout Optimization

Four different scenarios were conceptually planned and implemented for layout optimization in wind farm for considering Soke Region climate conditions.
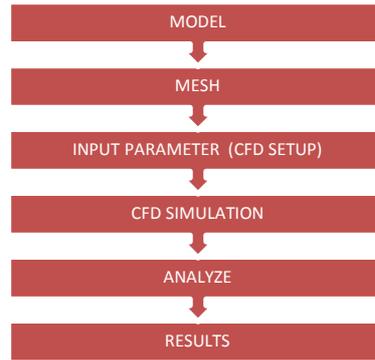
Fig. 1. CFD processing and simulation in the ANSYS Workbench

Configuration 1: Wind turbines placed one behind the other (in-line).
Three wind turbines are aligned one behind the other as shown in Figure 2. The distance among turbines was selected as 5m.
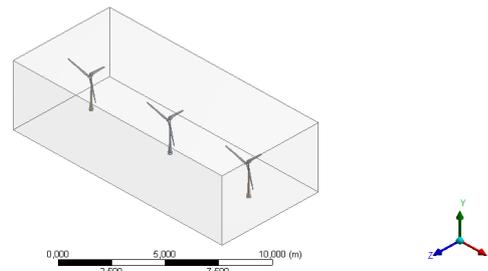
Fig. 2. Configuration of the wind turbines placed one behind the other

Configuration 2: Wind turbines placed one beside the other (side-by-side).
Alternatively, the turbines one beside the other, to the direction of the headwind were placed (Figure 3). The distance among turbines was selected as 5m.
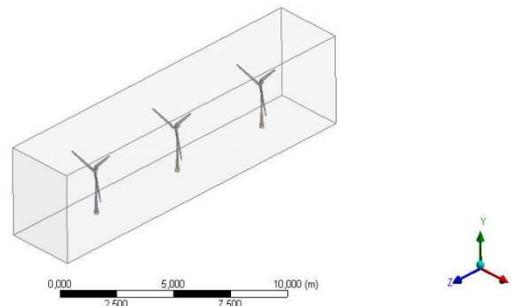
Fig. 3. Configuration of the wind turbines placed one beside the other

Configuration 3: Wind turbines placed along a triangular.
The third configuration is to place the turbines one beside the other, along a triangular, to the

direction of the headwind, as shown in Figure 4. Most commercial wind farms use such configurations. The distances in x- and y- axes were selected as 5m to each other.
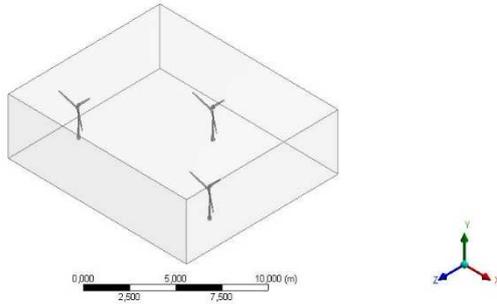
Fig. 4. Configuration of the wind turbines placed along a triangular

Configuration 4: Wind turbines placed along a diagonal.

Three wind turbines are placed along a diagonal as shown in Figure 5. The distances in x- and y- axes were selected as 5m to each other.
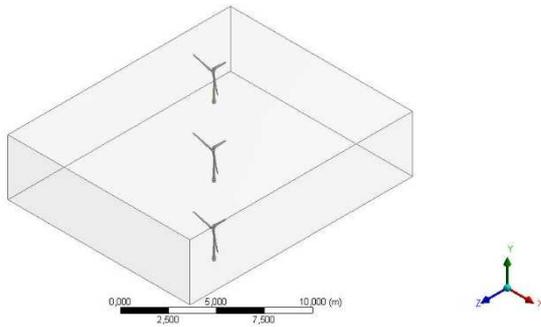
Fig. 5. Configuration of the wind turbines placed along a diagonal

2.4. Mathematical Calculations

The power calculations for each configuration in the wind farm can be determined using the below equation:

$$P = \frac{1}{2} \times C_p \times \rho \times A \times V^3$$

Where;
P the electrical power produced (W),
ρ air density (kg/m³),
A swept area of wind turbine (m²),
V wind velocity (m/s),
C_p the power coeffcient.

$$R = 1.38m \quad A = \pi \times (1.38)^2 = 5.983m^2$$
$$\rho = 1.225 kg/m^3$$

$Cp = 0.4$ [1].

$$P = \frac{1}{2} \times 0.4 \times 1.225 \times 5.98 \times (7.283)^3 = 566.26W$$
$$P = 0.000566MW$$

The power obtained from one wind turbine in Soke Region is 3MW. The rated power obtained from the wind turbine for analysis is 0.000566MW. The ratio between them is 5,297.918.

Wind velocity in Soke Region was taken as 10.56m/s. In present study, by assuming that turbine effciency (C_p) is 40% [1] and the produced turbine power can be calculated as:

Configuration 1: Wind turbines placed one beside the other.
Velocity of each wind turbine is equal to 5.376 m/s. Therefore;

$$P = \frac{1}{2} \times 0.4 \times 1.225 \times 5.98 \times (5.376)^3 = 227.75W$$
$$P = 0.00023MW$$
Total power ;
$$P_T = P \times 3 = 0.00023 \times 3 = 0.00068MW$$
$$P_T = P \times 5,297.918 = 0.00068 \times 5,297.918 = 3.61MW$$

Configuration 2: Wind turbines placed one behind the other.
Velocity of each wind turbine=5.528 m/s

$$P = \frac{1}{2} \times 0.4 \times 1.225 \times 5.98 \times (5.528)^3 = 247.62W$$
$$P = 0.00025MW$$
Total power:
$$P \times 3 = 0.00025 \times 3 = 0.00074MW$$
$$P_T = P \times 5,297.918 = 0.00074 \times 5,297.918 = 3.93MW$$

Configuration 3: Wind turbines placed along a triangular.
Velocity of each wind turbine=5.633 m/s. Therefore;

$$P = \frac{1}{2} \times 0.4 \times 1.225 \times 5.98 \times (5.633)^3 = 262.00W$$
$$P = 0.00026MW$$
Total power:
$$P \times 3 = 0.00026 \times 3 = 0.00078MW$$
$$P_T = P \times 5,297.918 = 0.00078 \times 5,297.918 = 4.16MW$$

Configuration 4: Wind turbines placed along a diagonal.

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Velocity of each wind turbine=6.037m/s. Therefore;

$$P = \frac{1}{2} \times 0.4 \times 1.225 \times 5.98 \times (6.037)^3 = 322.51W$$

$$P = 0.00032MW$$

Total power:

$$P \times 3 = 0.00032 \times 3 = 0.00097MW$$

$$P_T = P \times 5,297.918 = 0.00097 \times 5,297.918 = 5.13MW$$

3. RESULTS

In this study, four types of wind turbine layout optimization were analysed using FEA-CFD Analyses. Since wind speed is the most crucial contributor to the power harvesting capacity of the wind turbines, the focus of study was obtaining the wind speeds on blades for each configurations.

Power calculations were performed for wind farm configuration types.

(a)

(b)

(c)

(d)
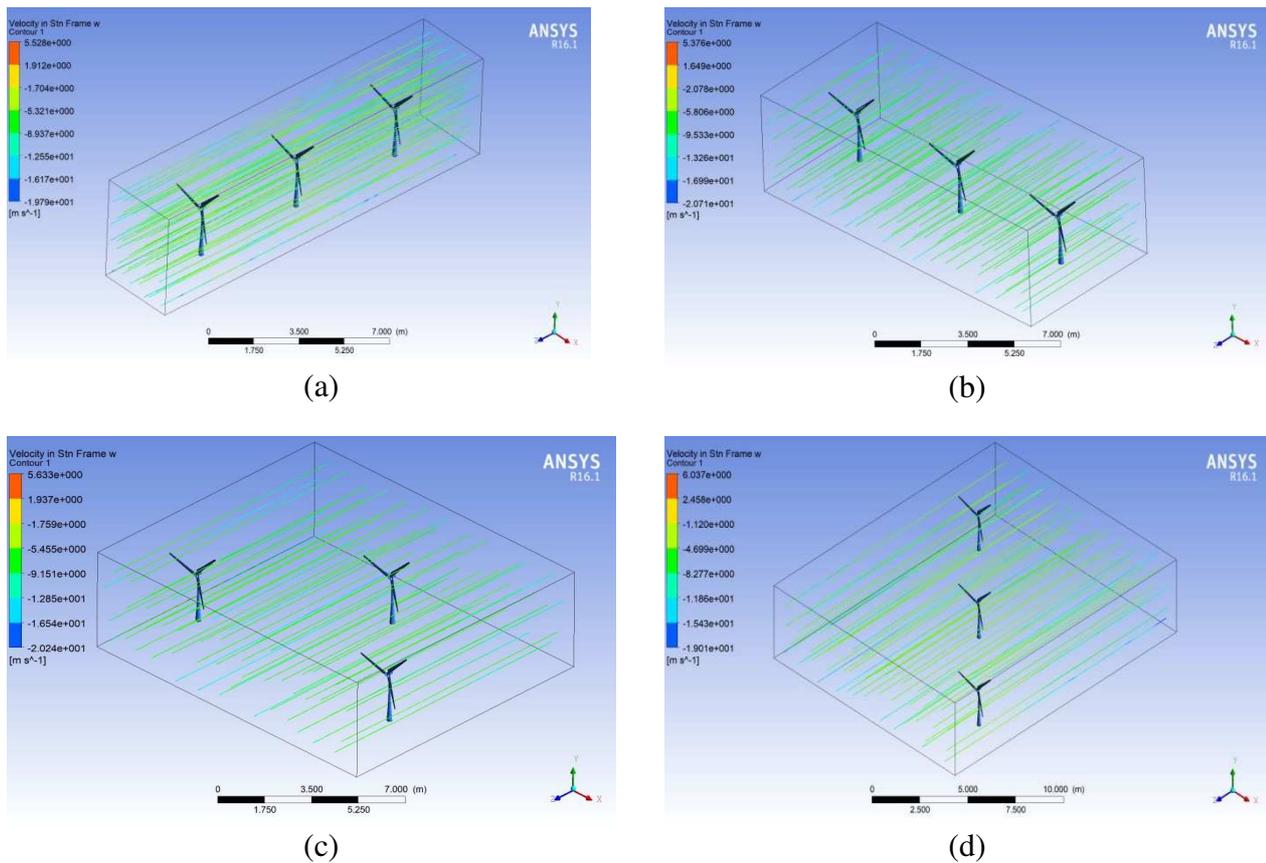
Fig. 6. The results of wind speed distribution on (a) Configuration 1, (b) Configuration 2, (c) Configuration 3 and (d) Configuration 4

Power production results for wind farm configuration types are given in Table 1. It is observed that diagonal and triangular type layouts produced more power than the others.

Table 1:

Power Production Results for Wind Farm Configuration Types

Wind Farm Configuration Types	Power (MW)
Configuration 1	3.61
Configuration 2	3.93
Configuration 3	4.16
Configuration 4	5.13

The results from CFD Analyses for the wind farm configuration types are depicted in Figure 6. It is understood that wind speed values are increasing in diagonal and triangular layouts.

4. CONCLUSION

In this study, four different configurations such as in-line, side-by-side, triangular and diagonal were conceptually planned and implemented in simulations. The weather data for Soke Region were obtained. These data were used as an input to CFD calculations. CFD computations were conducted by Fluent Analysis Software in Ansys in order to find the best pattern.

From the results, the following conclusions can be withdrawn;
1) The diagonal and triangular type layouts produced more power than the others (in-line and side-by-side).
2) The wind speed values are increasing in diagonal and triangular layouts.
3) The diagonal type wind turbine harvested the power of 5.13 MW. When comparing with other layouts, diagonal type wind turbine produced the highest power.
4) It is suggested to investigate the performance of CFD simulation by applying real environmental boundary conditions and shapes.
5) Furthermore, the calculation performance of CFD with two enclosure types such as rectangular and square should be investigated

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ANALIZA DINAMICĂ DE CALCUL A FLUIDELOR TURBINELOR EOLIENE PENTRU REGIUNEA SOKE

Rezumat: Turbinele eoliene sunt dispozitive electro-mecanice foarte importante care transformă energia cinetică a vântului în energie electrică. Datorită configurațiilor necorespunzătoare în proiectarea și aspectul turbinelor eoliene, energia nu poate fi recoltate eficient. Prin urmare, acest studiu sa concentrat pe optimizarea a patru configurații diferite folosind Calculul dinamicii fluide computerizate (CFD). Modelele de stare solidă ale turbinelor eoliene au fost create și toate componentele au fost asamblate folosind Autodesk Inventor. Patru configurații diferite, cum ar fi în linie, side-by-side, triunghiulare și diagonale au fost planificate conceptual și implementate în simulări. Au fost obținute datele meteorologice pentru regiunea Soke. Aceste date au fost utilizate ca o contribuție la calculele CFD. Calcularea CFD a fost efectuată de Software-ul Fluent Analysis în Ansys pentru a găsi cel mai bun model. Aceste configurații au fost testate utilizând valorile vitezei vântului obținute din datele meteorologice. Mai mult, a fost investigată performanța de calcul a CFD cu un tip de incintă dreptunghiulară. Rezultatele obținute au arătat că modelele diagonale și triunghiulare au o capacitate de recoltare mai bună decât celelalte.

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