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Modeling and Simulation of the Performance of Wind Turbines under Iraqi Weathers Conditions

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Abstract **- Nowadays, generation of power becomes very expensive and therefore finding an alternative source for producing power is recommended. Therefore, wind energy can be considered a key solution due to having low cost. This paper focuses on the design of small wind turbine with a horizontal axis that contains diffuser, shroud, and nozzle. The blade length is 0.6 m to be appropriate for producing energy commensurate with the climatic conditions in Iraq, by using a 3D-numerical simulation, non-compressive, viscous, turbulent flow around a turbine, all are sets to become an input data to the model created by using ANSYS-FLUENT. Researches are impact on three different sorts; diffuser only, diffuser Shroud and Diffuser, Shroud, Nozzle. The blade angle is taken from 0° to 14° on fluid flow and the energy generated for the wind velocity range from (1-5) m/s. Drawing a contour for the pressure and velocity on the surfaces of the blades and diffuser, also displaying the results of the turbine's generated power. The results also confirmed that the efficiency of the torsion angle of the wind turbine increases as the torsion angle grows of the blade to 10° degrees, and any additional increase in this angle negatively affects the generated energy.**

Keywords: Wind power, covered turbine, wind speed, blade tip speed, turbulent flow.

I. INTRODUCTION

Due to the development of science and technology, that the world has become a witnessed since the beginning of the last century, as well as the significant increase in the world's population and the improvement in living standards that accompanied this development, most industrialized countries and even developing countries have generally increased their population growth. Therefore, the demand for electrical energy consumption has increased, as it represents the main artery of sustainability in contemporary life, and taking into account the role of new and renewable energy for this, the production of renewable energy has become the key to maintaining the current demand for energy and meeting future needs [1]. The global distribution of energy resources required many countries to resort or storing their reserves of fossil fuels and search for other sources of energy because they were the cause of many crises that the world witnessed in the seventies of the last century. All of these reasons prompted energy workers to search for efficient alternative sources. It is acceptable on the one hand and reduces polluting emissions to the environment on the other hand, as it plays a major role in the future as it is sustainable because it is renewed from natural processes [2]. Therefore, it was necessary to go to alternative sources of renewable energy, which are characterized by having a small negative impact on the environment, the simplest of which is wind energy [3]. Wind energy is one of the early energy sources that man used to double the production capacity that was dependent on some human beings, and humans used wind energy in the sea to drive sailing ships. However, windmills did not begin to spread as an alternative to oil-based energy until the oil crisis, since 1970 even today [4]. Wind energy is one of the most essential resources available for obtaining electricity. Many countries, particularly in Europe, employ it extensively. Figure 1 shows the capabilities of renewable energy in some countries of the world.

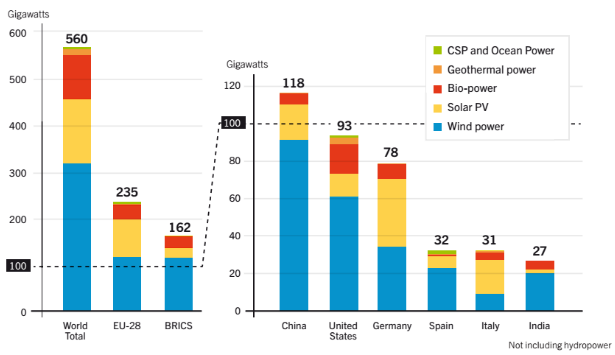

Figure 1: Renewable energy production capacities in the world [5]

1.1 Types of wind turbines and their advantages

There are several criteria for determining wind turbine design and what is most appropriate for a particular site. Wind turbines are classified into many categories depending on the type of blades and the way they are installed in terms of making the blades with fixed joints (fixed paddles) or making them move with a joint with rotation (Moveable paddles) however, the main classification depends on the type of

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rotation axis, and they're divided into two groups. Wind turbines with a horizontal axis (HAWT), Wind turbines with a vertical axis (VAWT). There are advantages and disadvantages for each type. The dominant feature of the VAWT can withstand winds coming from any direction. The blades are usually without any deviations bend along the axis, and as a result, they can be produced at a reduced cost. Because it rotates around the vertical axis, the generator can be positioned close to the ground, this lowers the cost of maintenance.

Table 1: Hours and Wind Energy Capabilities in the Middle East and North Africa Countries

Country	Number of load hours during the year
Egypt	3015
Morocco	2708
Amman	2463
Libya	1912
Iraq	1789
Saudi Arabia	1789
Algeria	1789
Tunisia	1789
Jordan	1483
Yemen	1483
Qatar	1421
Lebanon	1176
UAE	1176

1.2 The most important features of vertical turbines are:

Vertical axis wind turbines (VAWT): The direction of the axis is perpendicular to the direction of a wind, meaning that it operates in all wind directions, and it’s most important features [6]:

- Simple to install in terms of structure, blade design, easy maintenance and repair, and cheap compared to the same horizontal axis.
- It can easily rotate in any direction of the wind, meaning that it is flexible in a movement when changing direction, the movement.
- It needs a simple and inexpensive tower that can be installed in cities and on traffic roads.
- It has a low power factor compared to horizontal axis turbines.
- Do not need any system or machine to change the direction of movement.
- The large area of the feathers may cause problems when facing winds with high pressures.

Horizontal Axis Wind Turbine (HAWT): The rotation in this type is in successive levels with the direction of the wind, and the blades are usually fixed at a small angle relative to the direction of the wind to obtain a large power factor, as the principle of movement of this type of turbine depends on harnessed with variable speed rotor designs [7]. The most important features of horizontal turbines are:

- The efficiency factor is relatively high due to all the fans rotating at the same time because they are facing the wind at the same time.
- It requires space and height, and therefore it cannot be installed in cities.
- It is used when winds with low speeds.
- Somewhat complicated, so it is expensive.
- It is not possible to change the wind direction except by using a specific control system to control the blades.

II. DAWT COVERED TURBINE SPECIFICATIONS

The wind turbine comes from the Latin word “turbo”, which means “rotating body.” It is a device consisting of two parts, one of which is movable and the other fixed that converts kinetic energy from the wind into mechanical energy, and then converts it to electrical energy. Table 2 shows the specifications of the turbine that are studied in this paper [8].

Table 2: Specifications of the turbine used in the study

Specification	Value
The Ratio of Rotating Rotor with a Generator	1:1
Rotor’s diameter	1200 mm
Blade’s length	600 mm
Total Blades	3

2.1 Twist Angle

The bending angle depends on the TSR, and the impact angle depends on the blade, as the tip of the blade does not coincide with the root of the blade. The blade must be rotated at an angle rather than flat, to obtain good lift force, the airflow must reach the blade at an appropriate angle. The greater the angle of inclination tends to give the maximum lift, and therefore greater torque [9]. The torsion angle of the blade here refers to the torsion angle or the angle between the pilot's chord line and the rotating plane of the blade. Table 3 shows the different angles studied in this research [8].

Table 3: Different angles studied in this paper

Case	Twist angle
1	0°
2	6°
3	10°
4	14°

2.2 Wind speed at selected locations

The data of the wind speed are collected from seven meteorological stations in Iraq to determine the wind speed distribution at high 50 meters. As wind speed increased in

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value when heading towards the southern region of Iraq due to the flattening of the earth's surface. The locations of Basra and Nasiriyah were the best in terms of wind speed, especially in the summer.

These locations have average annual values of wind speed of around 5 m/s and more. While the sites that were selected and distributed in the center, north, and south of Iraq, recorded good wind speed, which indicates that Iraq has acceptable wind energy. 6.3 m/s, 5.4 m/s, 6.2 m/s respectively, and these rates are encouraging for its investment in the field of wind energy. Tables 4 show the annual rates of relative wind speed for different regions in Iraq, which are in the Nineveh governorate (Mosul, Tal Afar, Rabi'a) as well as Baghdad, Rutba, Nasiriyah and Basra. These data were collected for the period from 1981 to 2019 from the Global Wind Atlas [10].

Table 4: Averaged monthly wind speed at 50 meters high for Iraq's several regions for the period 1981 to 2019

Stations	Annual rate(m/s)
Mosul	4.3
Talafar	4.7
Rabi'a	5
Baghdad	5.4
Rutba	5.9
Nasiriyah	6.2
Basra	6.3

2.3 Controlling Equations

Continuity equation [11]

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0 \qquad (1)$$

X-Momentum

$$\frac{\partial(u^2)}{\partial x}+\frac{\partial(uv)}{\partial y}+\frac{\partial(uw)}{\partial z}=\frac{1}{\rho}\frac{\partial p}{\partial x}+\frac{1}{R_e}\left(\frac{\partial \tau_{xx}}{\partial x}+\right.$$

$$\left.\frac{\partial \tau_{xy}}{\partial y}+\frac{\partial \tau_{xz}}{\partial z}\right)+\rho(u'u'+u'v'+u'w') \qquad (2)$$

Y-Momentum

$$\frac{\partial((uv))}{\partial x}+\frac{\partial(\rho v^2)}{\partial y}+\frac{\partial(\rho vw)}{\partial z}=-\frac{1}{\rho\frac{\partial p}{\partial y}}+$$

$$\frac{1}{R_e}\left(\frac{\partial \tau_{xy}}{\partial x}+\frac{\partial \tau_{yy}}{\partial y}+\frac{\partial \tau_{yz}}{\partial z}\right)+\rho(v'u'+v'v'+v'w') \qquad (3)$$

Z-Momentum

$$\frac{\partial(\rho uw)}{\partial x}+\frac{\partial(\rho vw)}{\partial y}+\frac{\partial(\rho w^2)}{\partial z}=-\frac{1}{\rho\frac{\partial p}{\partial z}}+\frac{1}{R_e}\left(\frac{\partial \tau_{xw}}{\partial x}\right.$$

$$\left.+\frac{\partial \tau_{yw}}{\partial y}+\frac{\partial \tau_{ww}}{\partial z}\right)+\rho(w'u'+w'v'+w'w') \qquad (4)$$

2.4 Steps of Analysis in ANSYS program

The first step: Import Geometry DAWT design, the design used by AutoCAD design program. 2D design of DHAWT can be shown in Figure 2. The shape can be designed by ANSYS software, using ANSYS Design Modular. Or by other design software such as Solid Works after designing a horizontal axis wind turbine, HAWT be simulated to determine the pressure, airflow, and speed on that turbine. There are instances when a mistake occurs, and when an error occurs, the source of the error must be identified, a solution devised, and the system re-simulated [12]. The data analysis process will continue if no errors are found, the turbine blade is 0.6 meters long. The blade angle varies from 0° to 14°. To assess this design, must first create it AutoCAD. To see the results in CFD and then can change from 2D to 3D design [12].

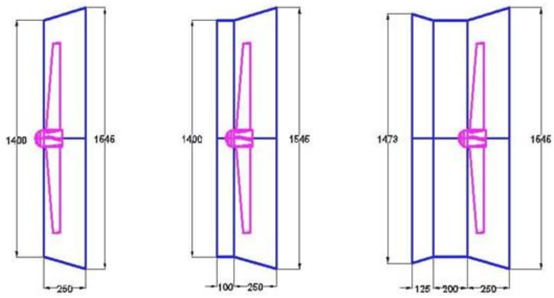

Figure 2: Dimensions of the different shapes of the diffuser

III. RESULTS AND DISCUSSIONS

From the results, it was proved that the shrouded wind turbines have produced the most power at low wind speeds, and their performance is increased, there has been a lot of research into the technology that can be utilized to improve the turbine's performance in this case by installing a diffuser, to boost the rotor's mass flow. Therefore, the energy generated by wind turbines is also increased, as compared to conventional wind turbines [13].

3.1 The results when blade angle 10°

One of the objectives of the current study and its importance is to investigate the factors that affect the enhancement of energy capture capabilities in wind turbines, the most important of which is the angle of the blade (the shape of the blade design) when increasing its value and its impact on energy production, as well as the shape of the cover that surrounds the turbine, the study shows that these factors have an effect direct impact on wind turbine performance that will lead developers and researchers to focus on it. Hence

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knowing what are the highest priority factors that must be taken into consideration to improve the new generations. Figure 3 shows the distribution of pressure and speed on the turbine blade when the wind speed is 2 m/s and the rotational speed is 280 rpm in the case of turbine only.

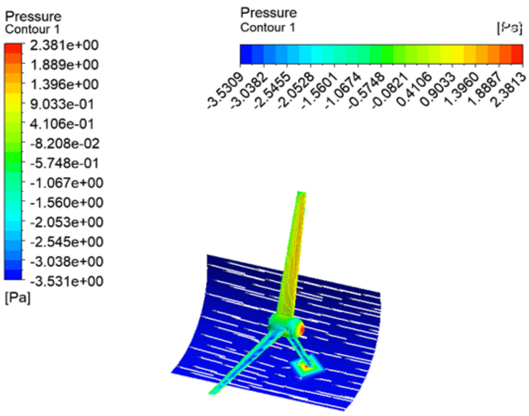

Figure 3: Velocity and pressure distribution on the turbine blade when the velocity of wind is 2 m/s and a rotational speed is 280 rpm

3.2 Diffuser Wind Turbine

Wind turbines covered with a diffuser at 10° angle demonstrated a boost in power as compared to wind turbines at 6° angle under the same wind conditions by taking the effects of five values of wind speed, and Figure 4 shows the distribution of pressure and speed on the turbine blade when the wind speed is 3 m/sec and the rotational speed is 385 rpm. note that the percentage increase in this case at angle 10° compared with the same case of the turbine (Diffuser) at angle 6° is about 18%. Because of the angle effect, the lower pressure at the diffuser outlet in this cause a greater volume of air to be pumped into the Diffuser wind turbine through the wind turbine.

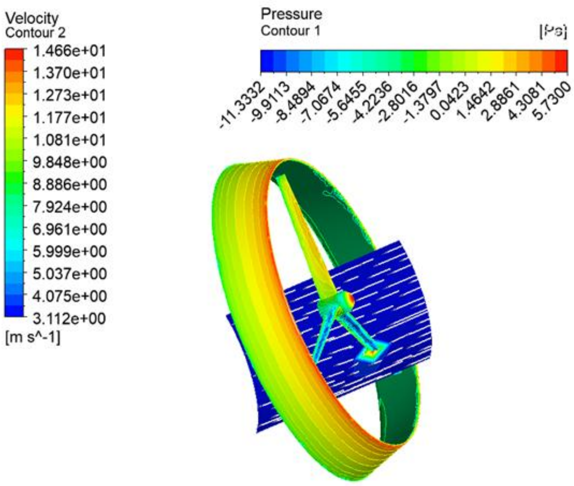

Figure 4: Velocity and pressure on the turbine blade when the velocity of wind is 3 m/s and a rotational speed is 385 rpm at blade angle of 10°

3.3 Shroud wind Turbine-Diffuser

Noticed the increase in power in the case of shroud wind Turbine-Diffuser, which is slight in this case compared to the case of the turbine (Shroud-Diffuser) at angle 6°, it is about 1.5%. Figure 5 shows the distribution of pressure and velocity streamline on the turbine blade when the wind speed is 4 m/s and a rotational speed is 450 rpm.

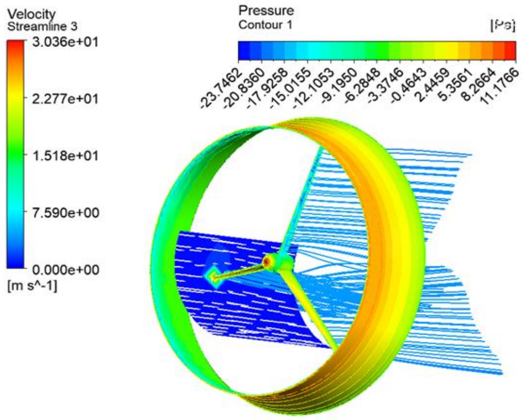

Figure 5: Velocity and pressure on the turbine blade when the velocity of wind is 4 m/s and a rotational speed is 450 rpm at blade angle of 10°

3.4 Shroud Nozzle Wind Turbine-Diffuser

The purpose of the development of the diffuser structure is to collect and accelerate winds by taking advantage of different flow characteristics, by eddy formation in the low-pressure region, flow by eddies, etc., for the inland or circumferential flows of the turbine cap. As a result, a shrouded wind turbine with a flanged diffuser showed a 19% increase in power at the corner, while Figure 6 shows the distribution of pressure and speed on the turbine blade when the wind speed is 1.5 m/s and the rotational speed is 155 rpm.

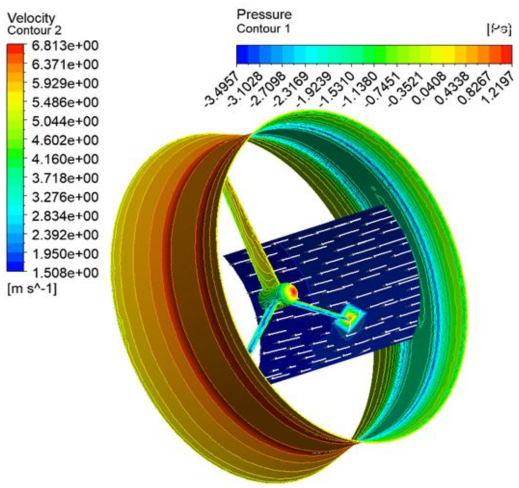

Figure 6: Velocity and pressure on the turbine blade when the velocity of wind is 1.5 m/s and rotational speed is 155 rpm at blade angle of 10°

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Figure 7 shows a comparison between the wind turbine results for all cases at an angle of 10°.

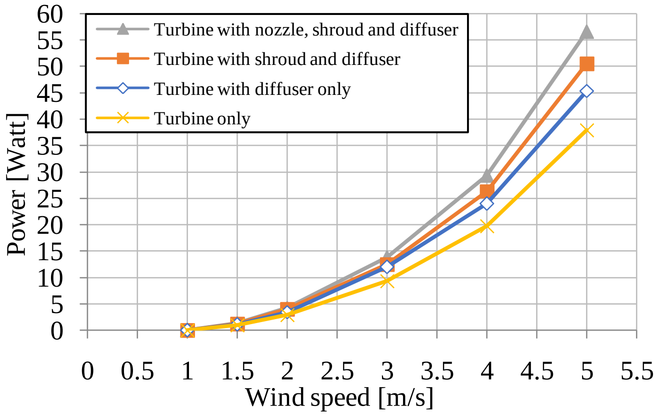

Figure 7: Results of turbines are compared for all cases at angle 10°

IV. CONCLUSION

The results of finite element models have been carried out successfully to show the behaviour of diffuser-enhanced wind turbines in all cases of the turbine, as well as wind speed in Iraq, which these results were obtained and discussed as follows:

1. The findings demonstrated that any form of diffuser presented in this study might be used, the energy generated in varying proportions, and that the greatest power can be obtained by adding Shroud Nozzle-Diffuser with Shroud, and 21% compared to Diffuser.
2. The results indicate that the capacity of the wind turbine increased when the angle of the blade varied from 0° - 10°, and any additional raise in this angle negatively affects the generated energy. It was noted that at 6° angle in the case of Diffuser, the capacity increases by 53% comparing the 0° angle, and in the case of Nozzle power, the capacity increase by 48% in comparison to the 0° angle.
3. It has been proven that the covered wind turbines have improved in performance when the wind speeds are low, and the wind turbines will produce maximum power. Also, the results showed that the diffuser has ability to increase the power from the wind turbines up to 50%.
4. The study shows the possibility to benefit from a wind energy in Iraq, but in a limited way (i.e. low energy for simple uses) to generate clean energy from wind turbines.
5. The effect of turbine edge can directly enhance the efficiency of the turbine by reducing pressure area and increasing speed, as the turbulence increases the energy generated by wind turbines.

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