Kingdom of Saudi Arabia

Prince Sattam bin Abdulaziz University

College of Engineering

Mechanical Engineering Department

DESIGN AND ANALYSIS OF HORIZONTAL AXIS WIND TURBINE AT ALKHARJ

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ABSTRACT

Wind energy is a kind of renewable energy source available in nature with no pollution, less risks and does not produce waste during electrical power generation. The Kingdom of Saudi Arabia has started a program of using wind energy in its existing energy portfolio. Accordingly, the campaign for wind energy resource assessment, wind farm design, optimization, and power grid system integration studies has begun. The Kingdom aims to increase its renewable energy production to 60 gigawatts, including 40 GW from solar energy and 20 GW from wind and other sources by 2030. The main objective of this project is to design and analyze a horizontal axis wind turbine at Alkharj to produce 1 MW power in support of the vision 2030. In this project the design of the proposed wind turbine was made by considering the most relevant design parameters such as available wind speed at various heights for Alkharj, blade length, airfoil and the aerodynamic forces on the blade, rotor diameter, swept area, tower height, nacelle components such as shaft, coupling, bearings and gearbox, Also, the wind performance calculations were done using wind resource data obtained from NASA at 50m height. It was found that the turbine will produce maximum and minimum average power outputs in the months of July and September, respectively. The design constraints, standards and safety related to this project were provided.

OBJECTIVES

- Obtain the long-term average wind speed for Alkharj at any height.
- Design the main components of the horizontal axis wind turbine to produce 1 MW using Alkharj wind data.
- Analyze the energy and power output from the turbine.
- Write the technical report for the design.

CONSTRAINTS

Our study takes into consideration the following constraints:

- Economy
- Ethical
- Safety
- Sustainability
- Environment
- Political
- Social
- Technical

DESIGN

To design horizontal axis wind turbine there area several considerations:

- Average wind speed
- Number of turbine units
- Swept area
- Number of blades
- Airfoil design
- Nacelle's parameters
- Tower height

Figure 1: Design of HAWT.

MATHEMATICAL MODELING

The power of wind turbine is given by:

$$P = 0.5 * Cp * \rho * A * V_d^3$$

The projection of wind speed at any height $\bar{V}$, is given by:

$$\bar{V} = 1.4701 + 0.02835 * 80 + 1.1733 * 80^{0.2246}$$

The shaft design is given by:

$$T = \frac{P*60}{2\pi N}, \qquad N = \frac{V_d * TSR * 60}{6.28 * R}$$

$$T = \frac{\pi}{16} * \tau * d^3$$

The Drag force is given by:

$$F_d = 0.5 * \rho * C_d * A * V_d^2$$

The Lift force is given by:

$$F_L = 0.5 * \rho * C_L * A * V_d^2$$

DESCRIPTION

Rotor: The rotor is made up of blades affixed to a hub. The blades are shaped like airplane wings and use the principle of lift to turn wind energy into mechanical energy.
Nacelle: The rotor attaches to the nacelle, which sits atop the tower and encloses the various components.
Blades: Blades can be as long as 150 feet half the length of football field
Foundation: Foundations are usually simple concrete blocks called footings that are placed under building walls and columns, or in the case of wind turbines, beneath the tower.
Gear Box: The rotor turns the low-speed shaft at speeds ranging from 20 revolutions per minute (rpm) on large turbines to 400 rpm on residential units.
Generator: Converts the mechanical energy produced by the rotor into electricity. Different designs produce either direct current or alternating current. The electricity may be used by nearby appliances stored in batteries or transferred to the power grid.
Tower: Because wind speed increases with height, taller towers allow turbines to capture more energy.

RESULTS

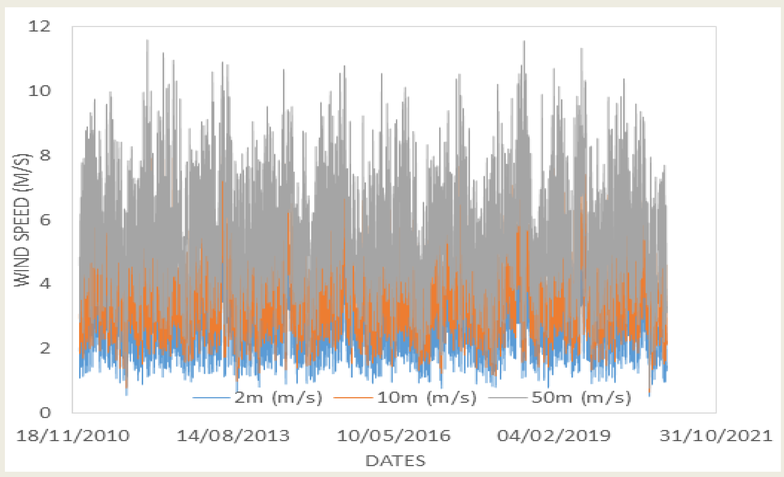

Figure 2: Wind speed data from NASA for each day for 10 years from 2011-1-1 to 2020-12-31 at heights of 2m, 10m and 50m in Alkharj.

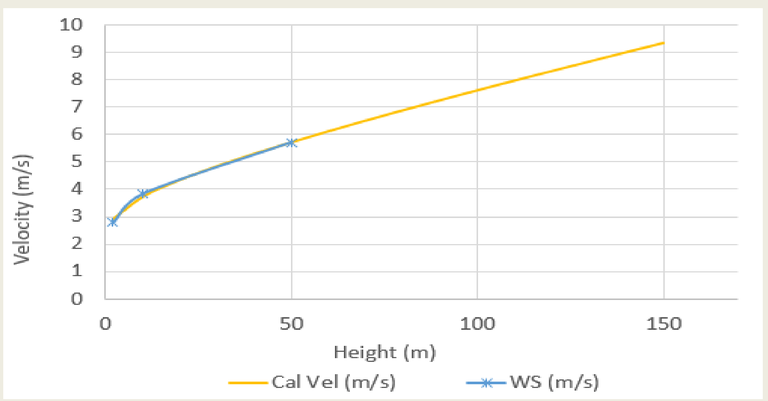

Figure 3: The projection of wind speed at any height.

DESIGN SUMMARY

Output power	1 MW
Type of wind turbine	Horizontal axis wind turbine
Tower height	80 m
Number of blades	3
Length of blades	34.33 m
Type of airfoil	DU 91-W2-250
Type of gearbox	1 planetary stage, 3 helical stages
Type of bearing	Tapered roller bearings
Rating life of bearing	4 years

POWER ANALYSIS

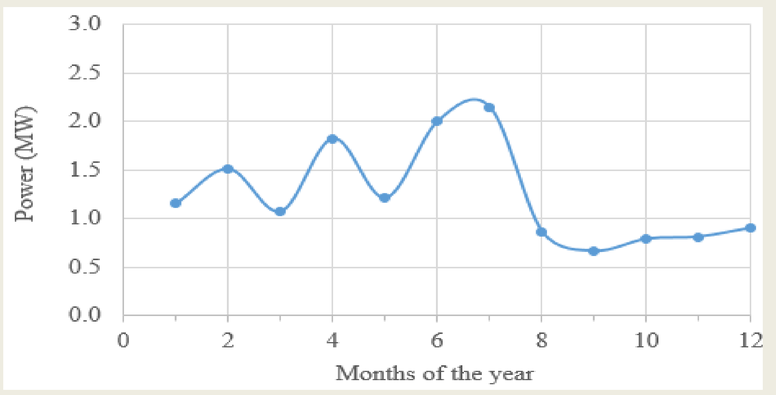

Figure 4: Monthly averaged output power of the wind turbine for the average year (2015) at 50 m height

CONCLUSION

- A comprehensive study of the design variables was made to have best choice for the design.
- The design of the parts used in this project was made to produce 1 MW power.
- The wind performance calculations were done using wind resource data obtained from NASA.