Design of a Wind Farm in Kuwait

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***Abstract*-Kuwait is considering diversifying its energy resources and not solely depending on oil and gas. Wind energy is one of the renewable energies being considered by the Government. By the year of 2030, the Government is planning to generate 120 MW from wind energy, which makes about 6% of the total renewable energy produced. Previous work conducted by former AUM senior students concluded that the area of the Abraq Al Habari has the highest potential for installing wind farm with wind power density (WPD) of 180 W/m^2 at hub height of 10 meters. This finding, however, was based on wind data for one year only (2013). In this project we collected data for three years to see if the wind speeds recorded in 2013 are consistent, year after a year. We will also have looked at best wind farm layout that would yield the maximum energy production at the minimum cost. Important factors such as terrain, and field roughness will be studied with the help of industry standard software such as WAsP and Windrose. Nevertheless, the cost analysis will be conducted to see how the project is**

I. INTRODUCTION

In our project, we will design a wind farm in Kuwait using WAsP software. A wind farm is a collection of wind turbines that are located on an open land. A former senior project team has already identified the most suitable site. That site is located in an area known as Abraq Al Habari, which is located on the west side of Kuwait. The selection of this site, however, was based on a data collected for one year only (2013). Once this established, we will feed the site wind data in addition to the terrain digital map and the field roughness map to WAsP. With this information, WAsP will help us identify the specific location, in Abraq Al Habari, suitable for installing the wind farm. It will also help in determining the number of turbines required to generate 120 MW and their best layout in the farm. In this project will also aim at estimating the total investment cost of the farm, electricity specific production cost per KWH, and the payback period of investments.

II. PROBLEM STATEMENT

This project is aimed at designing a wind farm in the area of Abraq Al-Habari to generate 120 MW of electricity. We will be interested in determining the number of turbines and the best turbines layout, considering the terrain and field roughness.

III. METHODOLOGY

- Collect hourly wind data for three consecutive years in Abraq Al-Habari, Kuwait.
- Analyze these data using Wiebull distribution function and compare WPD over these years to see whether the WPD is consistent.
- Background reading and literature survey of wind farm design and standards for selecting a site
- Install and practice wind farm design software such as WAsP and WindPro.
- Download terrain digital map for the area of Abraq Al-Habari from SRTM (Shuttle Radar Topographic Mission) 90m Digital Elevation Database and feed it as an input to WAsP
- Create a roughness map for the area of the Abraq Al Habari using WAsPMap Editor toinsert as an input to WAsP.
- Run WAsP to determine the best layout of the turbines, the required number of turbines, the cost involved, the total energy production, and the specific energy cost per KWH.
- Iterate by selecting different location within Abraq Al-Habari until the best location is obtained.
- Pick out the ultimate layout of wind turbines given the location.

IV. DESCRIPTION OF WIND FARM SITE

The wind farm site is selected based on several factors that are vegetation, far-away from the city, and availability of free open land. A former senior project analyzed three locations and chose the best site that fits the wind farm in all aspects. The ultimate location for the wind farm installation turned out to be Abraq Al- Habari that is located west side of Kuwait. As shown in the figure 7 below, it is located right above Al- Salmi. The main point of this location is that it has the highest wind speed of them all and satisfies all the factors too. Figure 8, shows the monthly mean wind speed measured at 10 m hub height for all three given sites. It is obviously shown that Abraq Al- Habari has the highest mean wind speed of them all.

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Figure 6-1: Kuwait Map Showing the Three Sites.

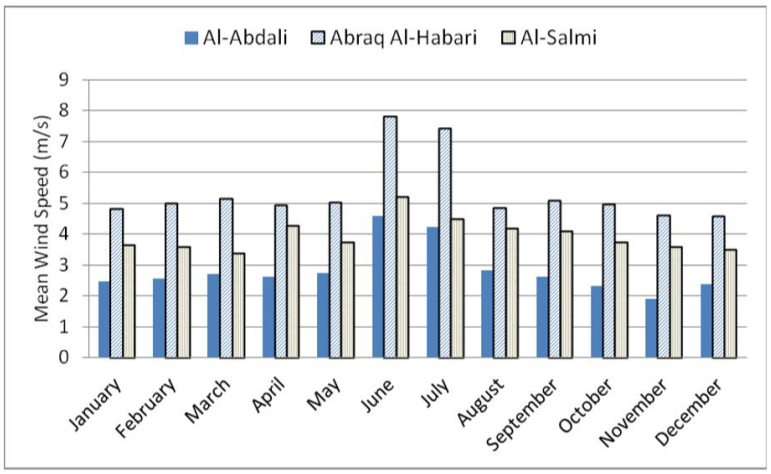


Figure 7-2: Monthly Average Wind Speed for the Three Sites.

V. WindRose

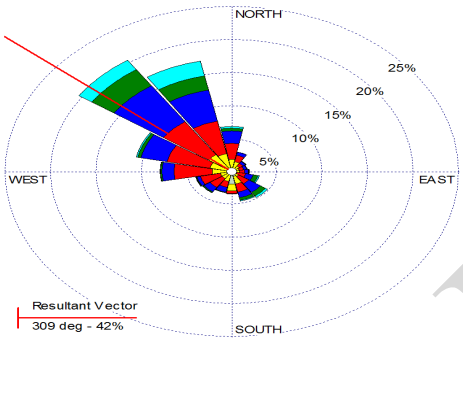


Figure 9-3: Wind Rose Results for 2012.

The first result we have is wind class frequency distribution. Figure 4.9-1 represents the wind class in percentage. As shown, from 3.6 and higher we can generate a moderate electricity power. This can be seen from the chart that the wind is strong enough for generating electricity for 71% of the time. The wind rose chart shown in figure 4.9-2 shows that the wind at this site in 2013 is mainly blowing from North-West direction. The chart shows the prevailing wind direction at 309 degree measured from the North in clockwise direction. The chart also indicates the wind blows from this direction around 42% of the time.

Figure 4.9-7 shows the variations of wind speed in m/s for the years 2012-2014. It is clearly shown that there is a minor difference of all speed sectors, except for the sector 2.1-3.6 in which 2014 had blown more often than the other years.

For 2012, the wind will be beneficial 69.7% of the time and for 2013, the wind will generate energy 71.4% of the time. At last, for 2014, the wind will blow 66.7% of the time.

From this it could be concluded that the turbines used at this site should be installed to face Northwest of the average angle 308° measured from North in clockwise direction. The turbines mostly are expected to work available 70% of the time. After all, we found the best degree to set the turbine towards which is northwest with 309 degrees and 42% of the time the wind is in this direction.

VI. WASP RESULTS

The first thing Wasp gave us is this roughness map. After that, we entered all the given data of the turbines to get the perfect layout within Abraq Al- Habari.

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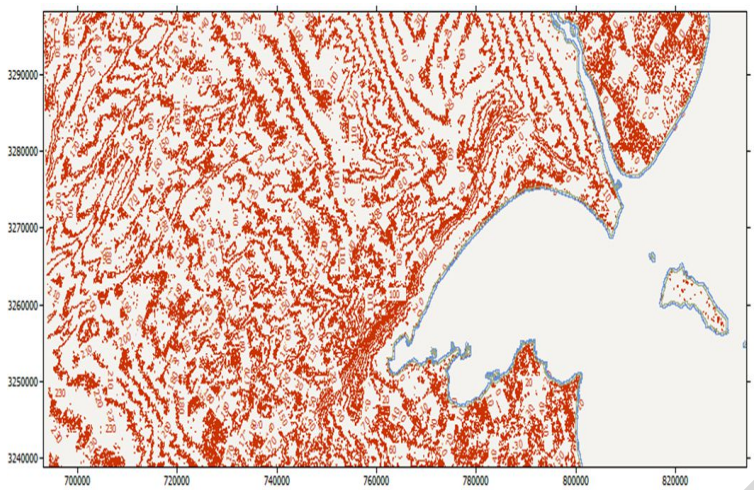


Figure 10-2: The Roughness Map Obtained From Wasp.

Abraq Al Habari Turbine Site:

- Hub Height a.g.l.: 95
- X Co-ordinate: 696119.5
- Y Co-ordinate: 3255890
- Elevation a.s.l.: 220

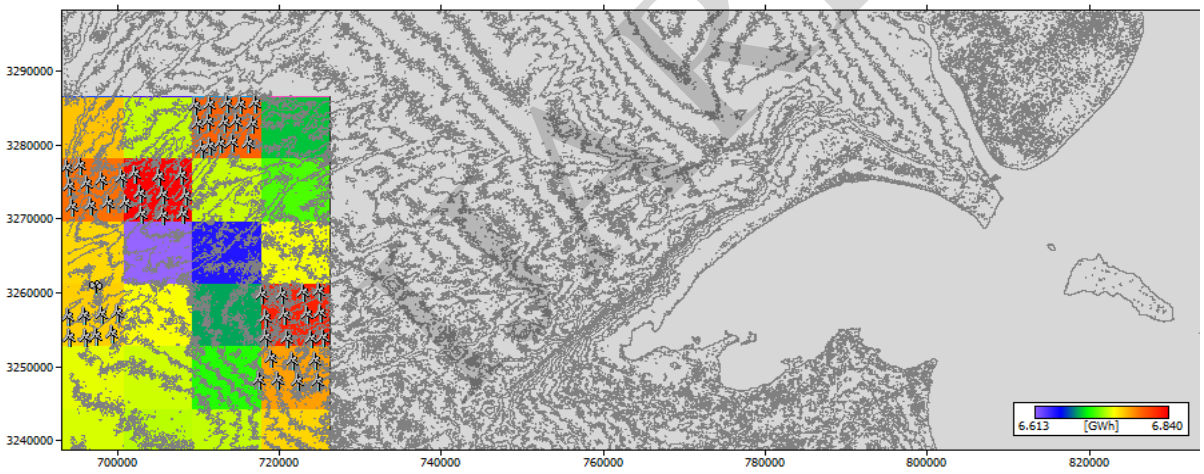


Figure 10.8-1: AEP (Annual Energy Production) Map of Abraq Al- Habari.

VII. ECONOMIC ANALYSIS

To calculate the performance of wind turbines and get all the project costs, we used a software called WindPower. WindPower is a computer program that calculates wind turbines performance and gives many outcomes such as mean power, annual energy outputs, and most importantly, the economics of a specific turbine at a mean wind speed at a given site.

From the first page of the program, we should load the file of the turbine chosen for our project. The turbine chosen by the former senior project has the following characteristics:

- G90 – 2MW
- Capacity: 2000 KW at 100 m height
- Turbine life = 20 years

Reference price per kilowatt-hour = 10 cents

The avereage wind speed in Abraq Al- Habari is 7.4 m/s. When entering the turbine data file, we get the power production at mean wind speed that equals to 814 kW equivalent to 0.814 MW. Our goal is to produce 120 MW so to get the number of turbines, we did the following:

- Number of turbines: $\frac{\mathbf{120MW}}{\mathbf{0.814MW}} = 148$ turbines.

Th following information we got from the previous work conducted is:

- ICC (Installation Capital Cost): 2151 $/kW.
- Annual Operation Expenses (AOE):

= 35 $/yr × 2,000 KW
= $ 70,000.

The calculations of all costs are shown below:

- Total turbine cost:

$= 0.68 \times 4{,}302{,}376$
$= \$\ 2{,}925{,}615$

- Installation fixed cost:

$= 0.32 \times 4{,}302{,}376$
$= \$\ 1{,}376{,}760$

After obtaining the exact numbers to plug into WindPower, we are interested in the costs presented at the mean wind speed. The reason for taking the average wind speed is because most of the time the turbine will be working on the average and not the maximum. By this way, we can get the optimum costs for the project.

- Total Cost/ Return of Investment (ROI): $\frac{Return}{TotalCost} = 2.50 \cong 3$.
- Payback period and annual income: 6.69 ≅ 7 years.
- Cost per-kilowatt hour (Profit): 4 $/ kW-hr.

VIII. CONCLUSION

In a nutshell, in this project we analyzed wind data and obtained the layout of the wind farm in Abraq Al- Habari. Also, we found the best area within Abraq Al- Habari to implement the wind farm using WAsP, Windrose, and WindPower computer programs. Furthermore, we found out the number of turbines needed to reach our goal which is 120 MW. Last but not least, we established the economic analysis for the entire project to see if it's profitable or not.

IX. FUTURE SCOPE

For the future, we hope that we look deeper into the project and continue with our calculations. Also, extra calculations should be made onto the turbines specifically such as the calculating the wake loss energy for each turbine. These types of calculations need Mechanical Engineers to dig deeper into it.

REFERENCE

[1] Khader, D. Al, Jassim, D., Bouzubar, N., &Zabout, O. Al. (2015). Potential of Adopting Wind Power in Kuwait.

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