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Economic Analysis of Wind Turbines in Oil and Gas Sector

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ABSTRACT: *Diesel generators or gas turbines located in the platforms usually do electricity production in oil and gas platforms. Using the above equipment, taking into account safety issues to prevent explosions and fires, as well as fueling them offshore, will be very expensive. In addition, the mentioned devices emit a significant amount of CO2 and NOx. Therefore, the use of renewable energy instead of fossil fuels can be much more economical and environmentally friendly. This study attempts to investigate the potential of using wind energy in the Persian Gulf and the feasibility and detailed economic analysis of using wind turbines on oil and gas platforms to provide part of the energy required. For this purpose, wind speed data are extracted from measurements at 10 meters, 30 meters and 40 meters above the ground. Averagewind speed for the mentioned levels as 4.45 m/s, 4.99 m/s and 5.34 m/s respectively. In addition, it givesthe annual power density as 128.36 W/m^2, 173.80 W/m^2 and 210.42 W/m^2. The results obtained by usingRETScreen software show that in this project with a life span of 30 years, the economic output of wind turbine systems is profitable, so that after 8.2 years, the entire cost of the project will return.*

KEY WORDS Renewable Energy, Wind Turbine, Offshore, Marine Platform, RETScreen

INTRODUCTION

Environmental issues and economic costs of using fossil fuels are the most important reasons for considering wind as an alternative energy source (Midilli, Dincer et al. 2006, Chapman, McLellan et al. 2018, Nazir, Ali et al. 2020, Abbasi, Shahbaz et al. 2022). Considering the windy nature of many regions inAfrica and Asia like Nigeria, India, Pakistan, Iran;etc, the development of wind turbine technologies can be justified . In recent years, many studies have been conducted on the potential of wind energy in different regions of Nigeria , India, Pakistan and Iran. These results show the necessity of investing and developing this technology in many areas (Ghobadian, Najafi et al. 2009). One of the places where energy supply is very important are oil and gas platforms (Gu, Li et al. 2021, Zereshkian and Mansoury 2021). Oil and gas platforms are the main structures of the offshore industry that provide the equipment and tools needed to extract and produce oil and natural gas in the seas (Devold 2013, Rui, Li et al. 2017). Different types of platforms are used depending on the water depth and their working conditions (Sadeghi 2007, Nouban, French et al. 2016).

The most common types of platforms.

In general, platforms can be classified into two types (Amaral 2020):

- Fixed foundation platforms that can only be used in its specific location.
- Floating foundation platforms that can be moved from one place to another.

Considering the shallow depth of the Persian Gulf, which is about 50 meters on average (Ghaemi, Mohammadpour et al. 2022), the platforms in this area are relatively similar to each other and are fixed platforms.

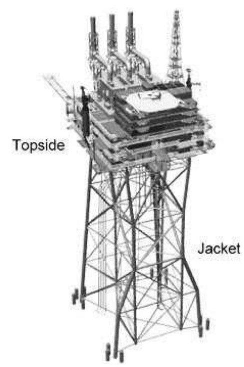


Figure 1. Fixed Oil and Gas Platforms (Ponte Jr 2021)

Supplying energy to these platforms is very challenging due to their distance from the coast. Offshore wind turbines are more expensive than onshore wind turbines and are more difficult to install and maintain (Bilgili, Yasar et al. 2011, Li, Wang et al. 2020). Offshore wind turbines must be stable against waves and be resistant to corrosive environment (Momber 2011). Of course, offshore wind power plantshave advantages. Considering that the wind is stronger at sea level (Holland 1980), these turbines can bemade bigger than onshore wind turbines, so the amount of electricity produced by each turbine increases.According to the above explanations, if oil and gas platforms are used for the installation of offshore windturbines, a significant reduction in the cost of construction and installation of offshore structures for the installation of wind turbines will occur.It is worth mentioning that the maximum height of marine platforms varies from 20 meters to 40 meters.Therefore, more wind potential will be available at these levels. The fuel used for offshore platforms is usually liquid fuel, which will cost a lot to transport from onshore. Economic factors, in addition to the production of large amounts of CO_2 and NOx, are the factors that justify the use of renewable energy in platforms.

Wind turbine system configuration models can be developed using existing software tools such as Matlabfor research purposes. Also, commercial software is available for free on the Internet for modeling the efficiency of new energies. RETScreen is one of the available commercial software that is available for free

(Lalwani, Kothari et al. 2010, González-Peña, García-Ruiz et al. 2021). This software has a wide range of capabilities that can be used to model the performance of power systems based on renewable energies. RETScreen is a Microsoft Excel-based software that models annual average energy flow with adjustment factors (Ramli, Wahid et al. 2017).

2. Case study description

Offshore extraction and transportation of oil and gas products have turned the Persian Gulf into one of the most important marine areas in the world. By installing a large number of oil and gas platforms in thePersian Gulf, Iran has a major contribution to the region's oil and gas production. It is clear that the amount of energy consumed in Iran's offshore industries will be a significant number per year. Reshadat oil field is one of Iran's oil fields, which is located 110 km southwest of Lawan Island.

Figure 2. Location of Reshadat Field

The development plan of the Reshadat offshore oil field includes four main wellhead, production and personnel accommodation platforms. This project consists of two wellhead platforms (W1, W2), a production platform (P), an accommodation platform (Q), a flare (F) platform and three bridges.

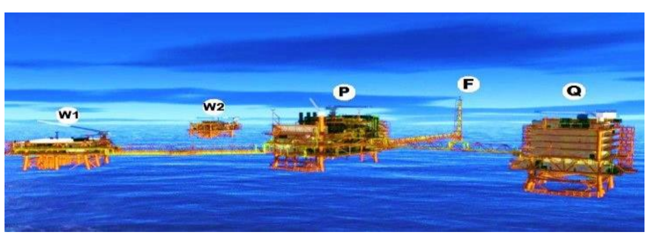


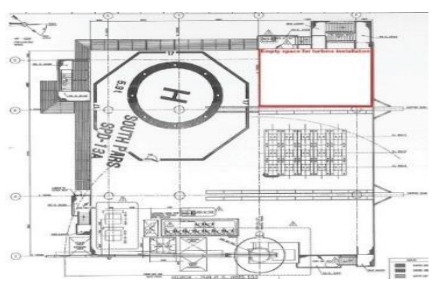
Figure 3. Position of Reshadat Platforms

A summary of the power consumption, dimensions and volume of the platforms for the Reshadat projectare described in Table 1.

Platform	Performance	Weight (ton)	Dimension (m)	Max. Power Consumption (kW)	Max. Platform Height from Sea Level (m)
P	Production	7117	3 Floor, 42 x 23	2051	34
Q	Accommodation	2853	6 Floor, 19 x 19	1623	39
W1	Wellhead	1456	2 Floor, 23 x 23	381	20
W2	Wellhead	1381	2 Floor, 24 x 23	435	20
F	Flare	74	5 x 5 x 5	-	12.5
P-Q	Bridge	53	71	-	19.5
P-F	Bridge	194	100	-	19.5
P-W1	Bridge	138	64	-	19.5

Table 1: Structural Properties of Reshadat Platforms

A 40m height is only available on the residential platforms described in the previous (Platform Q), and in otherplatforms, lower heights are accessible.



Due to the lack of space on the deck and using last floor for landing helicopter and loading by crane, theproposed wind turbine for the use on platform is the Vertical-Axis Wind Turbines (VAWTs).

Figure 4. Overview of Accommodation Platform

Due to the long length of the bridge between platforms, it is possible to install several vertical axis windturbines on communication bridges.

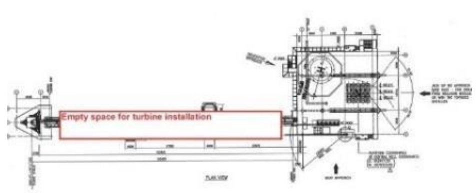


Figure 5. Overview of Wellhead Platform

3.Wind data

Due to the lack of access to wind data in the platforms, the official meteorological information of Kish Island has been used, which is largely indicative of the wind data in the area of oil and gas platforms in the Persian Gulf. The dominant winds of Kish Island are mostly western and southwestern winds. The winds usually change by the variation of sunlight's height or season. In Kish station, sensors for measuring the speed and direction of wind flow are installed at the heights of 10, 30, 40 meters, and each sensor records wind power data every 10 minutes (144 data per day). This information is collected and publishedby the new energy organization of Iran. In the following, using analytical relations, the conditions of eachstation for the construction of wind turbines have been investigated.

The following equation gives the average speed over a period.

$$\bar{U} = \frac{1}{N}\sum_{i=1}^{N} U_i$$

In this equation, "N" indicates the number of times the speed is recorded at the station and "U" indicatesthe speed measured by each sensor at any time.

Kinetic energy per unit of time or wind power is obtained from the following equation:

$$\bar{P} = \frac{1}{2}\rho A\left(\frac{1}{N}\sum_{i=1}^{N} U_i^3\right)$$

Where A is the air density and B is its impact area. Therefore, wind power per unit area or wind powerdensity is equal to:

$$\frac{\bar{P}}{A} = \frac{1}{2}\rho\left(\frac{1}{N}\sum_{i=1}^{N} U_i^3\right)$$

Similarly, the wind energy density per unit Area for a given extended time period (T=N Δt) is:

$$\frac{\bar{E}}{A} = \frac{1}{2}\rho\sum_{i=1}^{N} U_i^3 \Delta t = \left(\frac{\bar{P}}{A}\right)(N\Delta t)$$

Figure 4 shows the average energy density of each station in the months of a year.

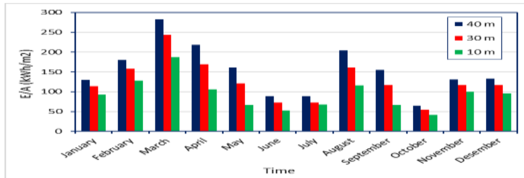


Figure 6. Monthly Average Energy Density

Energy pattern factor shows the ratio of average wind power to average wind speed.

$$E_{pf} = \frac{\overline{U^3}}{\left(\bar{U}\right)^3}$$

Wind power potential for installation of wind turbines is evaluated according to the criteria.

Table 2: Wind power criteria

Evaluation	Wind average velocity
Poor	Less Than 4.5 m/s
Marginal	4.5 - 5.4 m/s
Good to Very Good	5.4 - 6.7 m/s
Exceptional	More than 6.7 m/s

3. Statistical Analysis

Statistical analysis should be used to determine the potential of wind energy in a site. This analysis depends on the wind speed probability density function p(U). One way to define the probability density is as a function that expresses the probability of occurrence of wind speed between U_a and U_b as follows:

$$p(U_a \le U \le U_b) = \int_{U_a}^{U_b} p(U)dU$$

The total area under the probability distribution curve is given by:

$$\int_0^{\infty} p(U)dU = 1$$

If p(U) is known, the following parameters can be calculated: Mean wind velocity:

$$\bar{U} = \int_0^{\infty} U\, p(U)dU$$

Standard deviation of wind speed:

$$\sigma_U = \sqrt{\int_0^\infty (U - \bar{U})^2 \, p(U)dU}$$

Mean available wind power density:

$$\frac{\bar{P}}{A} = \frac{1}{2}\rho \int_0^\infty U^3 \, p(U)dU$$

The probability density function could be fitted on the wind speed histogram by scaling it to thehistogram area.Another important statistical parameter is the cumulative distribution function F(U) which represent thetime fraction or probability that the wind speed is smaller than or equal to a given wind speed (U'). It canbe shown that:

$$F(U) = \int_0^U p(U')dU'$$

In this research, Weibull probability density functions have been used in wind data analysis.

$$p(U) = \left(\frac{k}{c}\right)\left(\frac{U}{c}\right)^{k-1} \exp\left[-\left(\frac{U}{c}\right)^k\right]$$

Determination of the Weibull probability density function requires a knowledge of two parameters, k, shape factor and c, scale factor. Both these parameters are a function of wind speed (U), and standarddeviation of wind speed (σU).The cumulative distribution function of velocity u is denoted by the probability that the wind speed isequal to or less than U .the cumulative distribution of F(U) is given by:

$$F(U) = 1 - \exp\left[-\left(\frac{U}{c}\right)^k\right]$$

The parameters c and k are calculated based on the following empirical formulas, in this study empiricalmethod of Justus (EMJ) and empirical method of Lysen (EML) are used.According to this method of Justus, the values of k and c factors can be retrieved as function of themean wind speed and its standard deviation by using the following equations

$$k = \left(\frac{\sigma_U}{\bar{U}}\right)^{-1.086}$$

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$$c = \frac{\bar{U}}{\Gamma\left(1 + \frac{1}{k}\right)}$$

Where Γ is the normal Gamma function.

In method of Lysen, the Weibull shape factor (k) is calculated similarly to the EMJ, However, the equationof the scale factor is proposed in the EML under the following form:

$$c = \bar{U}\left(0.568 + \frac{0.433}{k}\right)^{-1/k}$$

RESULTS AND DISCUSSIONS

According to the relation between speed and power, wind speed is the most important factor affectingthe power produced. Even small changes in wind speed may lead to significant changes in power.

Table 3: Calculated wind parameters

Height	10 m	30 m	40 m
Annual Average Speed (m/s)	4.45	4.99	5.34
Annual Average Power Density P/A (W/m^2)	128.36	173.80	210.42
Annual Average Energy Density E/A (kWh/m^2)	1124.42	1522.49	1843.29
Energy Factor	2.37	2.28	2.25

Table 3 shows the values obtained for the Weibull coefficients using both mentioned methods.

Table 4: Weibull coefficients

Height	**10 m**		**30 m**		**40 m**	
constant	k	c	k	c	k	c
Justus Method	1.6	5.9	1.6	5.5	1.6	4.9
Lysen Method	1.6	4.7	1.6	4.4	1.6	3.9

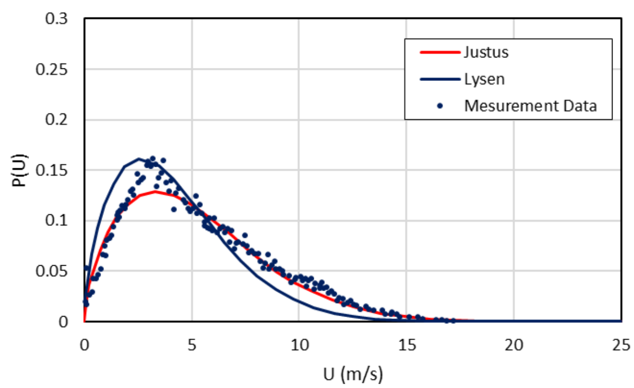

Figure 7. Weibull probability distribution at 40 m

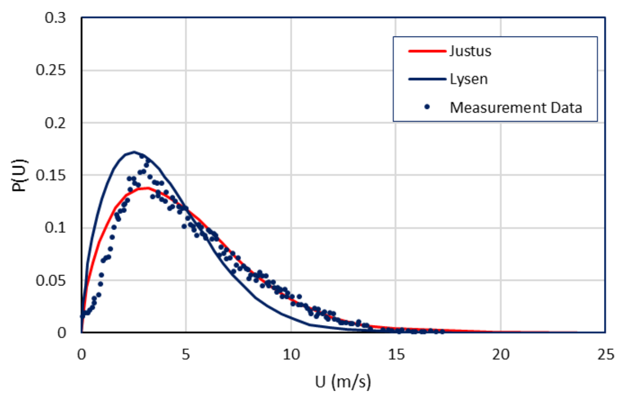

Figure 8. Weibull probability distribution at 30 m

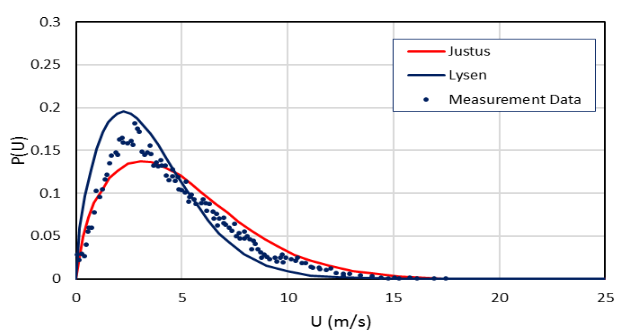

Figure 9. Weibull probability distribution at 10 m

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The following graphs are drawn for direct use of the data and statistical analysis of the data with the Weibull function obtained from the dual methods.

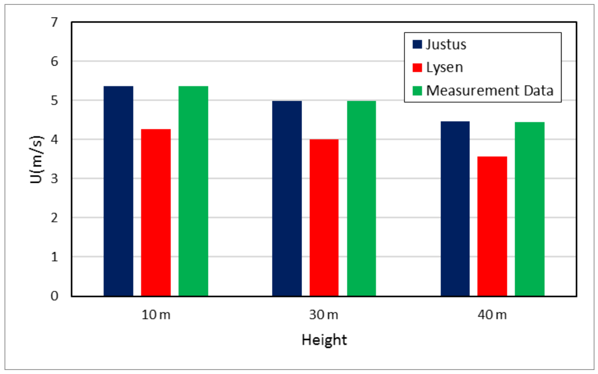

Figure 10. Annual Average Wind Speed

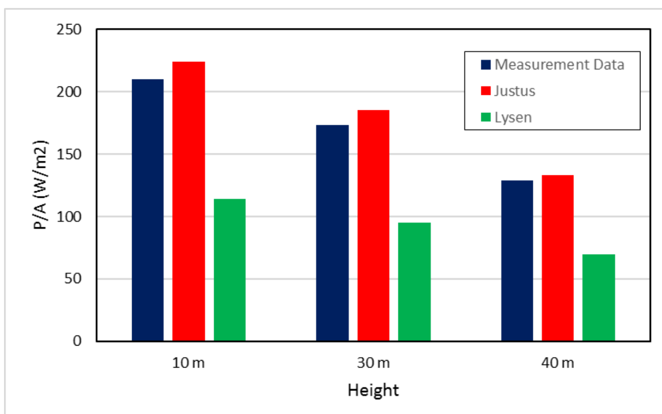

Figure 11. Annual Average Power Density

Application of wind turbine project data in RETScreen software is defined for Production of Power up to 3000 kWh in a project with 30 years duration. The connection type is network connected. Due to the lackof suitable space and safety issues, the vertical axis wind turbine is considered suitable for installation onthe platform. Electricity export rate by taking into account fuel cost and delivery to the platform is 0.62 USD per liters; In addition, according to the Iran energy balance sheet in 2013, the cost of transporting fuel by ship and transferring it to a storage tank on the platform specifies an equivalent of 12.4 cents perkilowatt. Each liter of gasoline is considered to be 0.832 kg. The cost of setting up a vertical axis wind turbine is considered to be approximately 2,500$ per kilowatt. GHG reduction is considered 10$ per ton of CO_2. In addition, the inflation rate of 15% is included in the software.

According to the above inputs, the economic results of RETScreen software are obtained as figure 10.

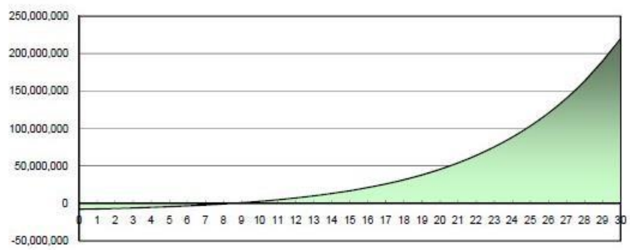

Figure 12. Cumulative Cash Flows

CONCLUSION

According to the obtained results, it can be stated that it is possible to install a medium-size of turbine (with an average capacity of 150 to 250 kilowatts) on the Reshadat oil platform. The results show that there is a better condition for turbine installation at 40m height. The highest average wind speed is observed in March and April, but in other months, there are also good wind conditions. The wind directionin the station is from southeast to northwest, and does not change over different months, which is a positive point for wind turbine installation. According to the economic outcomes of the RETScreen software output for the wind system, this project with a lifespan of 30 years is profitable so that after 8.2years the entire cost of the project will be returned. The total amount of power required on platforms with the communication bridge is 4055 kW. The total estimate of the lowest amount of produced powerby wind turbines on platforms is 3060 kW. Finally, according to the results and calculations it can be statedthat %75 of required power of Reshadat offshore platforms (as an example) can be provided by existing wind turbines on platforms.

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