

Assessment of off-shore wind turbines for application in Saudi Arabia

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ABSTRACT

This paper presents models and economic analysis of ten different wind turbines for the region of Yanbu, Saudi Arabia using the hybrid optimization models for energy resources (HOMER) software. This study serves as a guide for decision makers to choose the most suitable wind turbine for Yanbu to meet the target of 58.7GW of renewable energy as part of Saudi Vision 2030. The analysis was carried out based on the turbines initial capital cost, operating cost, net present cost (NPC) and the levelized cost of energy (LCOE). Additionally, the wind turbines were compared based on their electricity production, excess energy and the size of the storage devices required. The results show that Enercon E-126 EP4 wind turbine has the least LCOE (0.0885 \$/kWh) and NPC (\$23.8), while WES 30 has the highest LCOE (0.142 \$/kWh) and NPC (\$38.3) for a typical load profile of a village in Yanbu.

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1. INTRODUCTION

The working principle of a wind turbine is the conversion of mechanical energy to electrical energy. The wind rotates the perfectly designed blades to produce rotational kinetic energy, which in turn rotate a generator to produce electricity. The wind energy can be harnessed by means of offshore or onshore wind farms. The offshore wind farms built in the ocean uses the high wind speeds available in the ocean to produce electricity whereas relatively cheap onshore wind farms are built in the lands. The global wind energy council reported a rapid growth of wind energy technology which has led to a reduction of nearly 637 tons of CO₂ emissions globally in 2016 [1]. Wind as a renewable source has attracted lot of attention in the present decade, focused mainly to rapidly decrease the levelized cost of energy (LCOE) of wind power plants, and to decrease the operation and maintenance cost due to the availability of highly efficient wind turbines [2]. It is estimated that the cost of power produced by wind farms will be on par with the price of power produced by coal-fired power plants by 2020 [3]. The International Energy Agency (IEA) has predicted that, by the year 2050, nearly 18% of global energy demand will be met by wind energy [4].

The ever-growing population of the Kingdom of Saudi Arabia combined with rapid growth of industrial/commercial projects in this country has led to an exponential increase in electricity demand. To meet this demand and to diversify from using oil as the main source of power, the vision 2030 of the Kingdom envisions a long-term renewable energy (RE) program designed to balance the Kingdom's power mix and to reduce its carbon footprint. According to the National Renewable Energy Program (NREP) of the Kingdom [5], more than 35 parks will be developed across the Kingdom and the target of RE production is 58.7 GW by 2030. The target of the power production by the wind energy alone is around 16 GW. To expedite the execution of the RE projects towards these goals, preliminary studies have been carried out. According to

those studies, 13.5 GW of RE capacities will be integrated to the grid by the end of 2019. One of the wind farm projects in the Kingdom at Dumat Al Jandal with a capacity of 400 MW has established a world record with the lowest LCOE (1.99 cents per kWh) for onshore wind farm projects [5]. The economic feasibility of developing wind farms at Taif, a western province of the Kingdom of Saudi Arabia has been carried out in [6]. A decision making approach for renewable power generation evaluation for the Kingdom is available in [7].

Literature survey carried out in the next section indicates a techno-economic analysis of wind turbine applications for the region of Yanbu which has not been previously investigated. Yanbu is a place where the Kingdom is planning to build large wind farms and hence this paper attempts to compare various available wind turbines and provide a recommendation of the most suitable wind turbines for Yanbu using (HOMER) software. This paper presents the economic analysis of ten different wind turbines for the region of Yanbu using HOMER software. Analysis is carried out based on the wind turbines initial capital cost, operating cost, net present cost (NPC) and the LCOE. Additionally, the wind turbines are compared based on their electricity production, excess energy and the size of the storage devices required.

The contributions of the paper are as follows:

- To carry out techno-economic analysis of various wind turbines for a region of Yanbu in the Kingdom of Saudi Arabia using HOMER.
- Various scenarios including size of energy storage systems are considered.
- Several criteria were considered to determine wind energy system suitable for Yanbu region and recommendations are provided based on the techno-economic analysis.

2. LITERATURE REVIEW

Even though most of the wind farm projects are away from urban centers, a critical review of establishing wind turbines near urban areas has been carried out in [8]. The technical and other challenges of integrating large scale wind farms in European countries, the impact on the power industry, and the solutions are discussed in [9]. An analysis of wind speed and wind power density at different heights for a period of 36 months between 1996 and 1999 for the northwest coast of Saudi Arabia is discussed in [10]. The integration of intermittent RE sources to the grid has important advantages such as a reduction of total cost of fuel and a reduction of atmospheric pollutants, as well as disadvantages such as a degradation of the quality of power, lower reliability, lower stability, and the associated changes in power system design and management [11]. The comparison of different wind turbines based on cost and annual energy yield is carried out in [12].

A study conducted by Kuwait Institute of Scientific Research and Energy Research Center of Kuwait has revealed wind as the most viable option for desert regions when compared to solar energy due to factors such as humidity, dust, and suspended particles in air [13]. Since the turbine blades are continuously working and are exposed to the dust in the atmosphere, they experience tremendous amount of stress. An assessment of total suspended particles by using probability distribution has been carried out in [14]. Economic analysis of seven different wind turbines using HOMER is carried out in [15] and this study does not consider on or off-grid application. The potential of harnessing wind energy for different sites in Malaysia has been determined through economic analysis and annual energy yield, using the HOMER software in [16]. Homer software is used in literature for optimal designing and modeling of wind energy conversion system in [17] and hybrid energy system in [18]. Compared to other software's, HOMER provides detailed results for analysis and evaluation and can run many configurations and provides results in a very short time [19]. Techno-economic analysis for a farmhouse in Nigeria in [20, 21], for a primary school in Iraq in [22], and for a waste management in Najf city of Iraq in [23].

A simulation model for accessing the potential of wind power generation in a place called Kitka, Kosovo is carried out in [24]. The authors in [24] have considered the wind turbines to be manufactured by Amperax. An artificial intelligence approach for optimizing wind energy conversion system is available in [25]. Integrating renewable energy system to smart grid and the feasibility of supplying smart grid only with renewables is carried out in [26]. Wind speed forecasting models has been analyzed using ANN (artificial neural networks) in [27]. The prediction of the wind speeds and wind characteristics is carried out in [28]. Statistical analysis for wind turbines to overcome real time implementation challenges are provided in [29]. The price of wind energy is modeled as a regression model and an evaluation analysis of wind parks in Colombia is available in [30]. The evaluation of wind power for power production in Palestine to alleviate shortage of electricity is available in [31, 32]. Previously, the techno-economic viability of renewable systems (wind inclusive) has been carried out for several cities in Saudi Arabia including Yanbu [33], but no work has evaluated the suitability of different wind turbines for applications in Saudi Arabia. Literature survey indicates HOMER software is widely used for techno-economic analysis and a study of techno-economic analysis for the region Yanbu, in the Kingdom of Saudi Arabia, where wind farm are expected is not available.

3. METHODOLOGY

Several techniques can be used for techno-economic analysis of a RE system. One such tool is the micro-grid software developed by the Homer energy commonly known as HOMER. It is a tool widely used for a variety of applications [34, 35]. In this work, the simulation model was developed using HOMER. Input parameters to the HOMER include, wind speed data for Yanbu, electrical load profile for a typical village in Saudi Arabia, selected wind turbine parameters, cost of the wind turbine incurred for the life time of the project, system converter parameters, and selected battery and its parameters. To determine the capital cost of each wind turbine, the price index for wind turbines available in the US\$ is applied as shown in Figure 1. From Figure 1 and for the year 2019, the price index for wind turbine is 0.79 million US\$ per MW [36]. Results from the simulation model implemented using HOMER with this price index was compared for the ten different turbines.

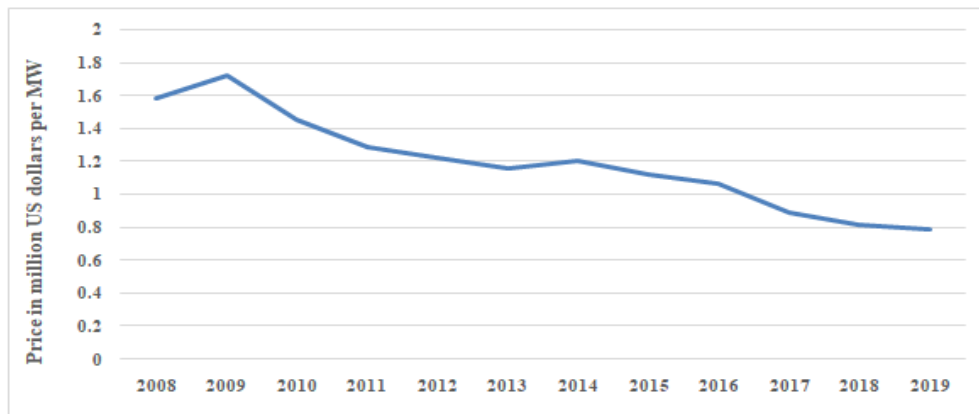


Figure 1. The price index for wind power production [36]

King Abdullah City for Atomic and Renewable Energy (KACARE) has obtained accurate wind speed data for different cities in Saudi Arabia, Yanbu inclusive [37]. These ground measurements obtained by KACARE are more accurate than the estimations based on the satellite. Figure 2 shows the average wind speed measurements for Yanbu at a height of 100m for a period of one year. The probability distribution function which fits the wind data was chosen with specific parameters given in Table 1.

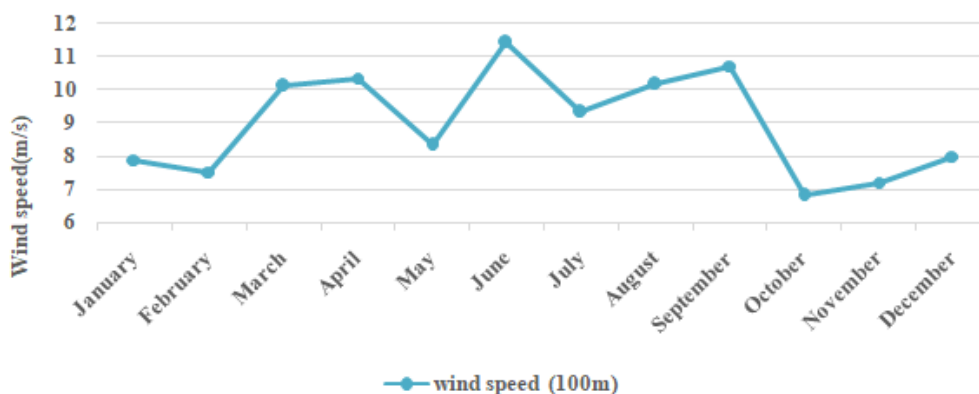


Figure 2. The wind speed data for Yanbu at the hub height of 100m for a period of one year

4. MODEL DESCRIPTION

The model used for simulation is shown in Figure 3. The base model was created in HOMER, with simple off-grid configuration with wind turbine, battery and converter. An economic consideration was based on the assumption that all the power generated is fed to the load. The capability of Homer was utilized to analyze the system for different types of wind turbines using the specifications summarized in Table 1.

Table 1 displays all model parameters and the assumptions that were made. The load selected for this research taking into account the weather fluctuations in Saudi Arabia. The estimated load for Yanbu is higher in the summer than in the winter. Previous research developed the load profile of typical village in Saudi Arabia [38], which was adopted in this research. The load has a scaled average energy of 48,435 kwh/day with a peak load of 5547.5kW.

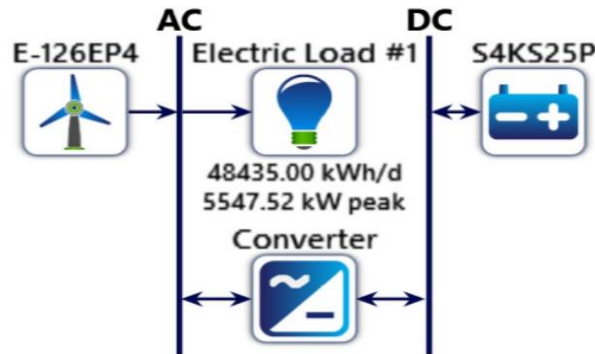


Figure 3. The wind turbine and battery model used for simulation in HOMER

Table 1. Basic parameters for the simulation model in HOMER

| Parameters | Selected values |
|------------------------------------|---------------------------------|
| Capital cost of wind turbine | Chosen based on Literature [38] |
| Lifetime of the wind turbine | 20 years |
| Weibull Factor (K) | 2 |
| 1hr autocorrelation factor of wind | 0.85 |
| Diurnal pattern strength (wind) | 0.25 |
| Hour of peak wind speed | 15 |
| Nominal discount rate | 6.86 |
| Expected inflation rate | 2.5 |
| Project lifetime | 25 |
| Capital cost of the battery | Chosen based on Literature [38] |
| Initial state of charge (battery) | 100% |
| Minimum stage of charge (battery) | 40% |
| String size (battery) | 1 |
| Capacity of the inverter | Chosen based on Homer optimizer |
| Lifetime of the inverter | 15 years |
| Efficiency | 95 |

5. RESULTS AND DISCUSSIONS

Numerous results were generated by HOMER in order to determine the viability of various wind energy schemes for the region of Yanbu. Table 2 shows the techno-economic analysis of the selected wind turbines that can be deployed for wind power projects in Yanbu. These turbines are among the commonly available wind turbines worldwide. By using HOMER, the most feasible wind turbines are the ones that minimize the cost of the project. In HOMER, the LCOE is an important parameter that describes the cost of power produced by the wind turbines over the project lifetime. It is actually the overall minimum price at which the electricity has to be sold in order to break even over the project lifetime. The results show that Enercon E-126 EP4 has the least LCOE and NPC, while WES 30 has the highest LCOE and NPC. However, certain factors need to be considered in choosing the right wind turbine, such as the initial capital cost, the operating cost, and the number of wind turbines required, which in turn affects the space required and thus the cost of the land for the project, and it also affects the noise level around the wind farms. In essence, choosing the most appropriate site for wind farm project is one of the fundamental parameters of any RE project, technically and financially.

Figures 4 and 5 show the electricity production per year from each wind turbine and the excess energy that may be available all year round. The results clearly show the importance of turbine selection for economic viability and electric power production. It can be observed that the highest energy was produced by wind flow 45 turbine while the least electricity recorded by XANT L-33 turbine. Similarly, these two wind turbines show the highest and lowest excess energy available, respectively. The excess energy can be used to supply a dump load or in some cases, it can be sold to the grid. In the future, the excess energy could also be used to charge batteries for electric cars. Figure 6 shown in the battery size in strings needed with each wind

turbine type considered. A string refers to the set of batteries in series. For this project, one string is equivalent to 4V battery.

Saudi Arabia has planned to install wind turbines as additional power generating scheme for the country, and since Yanbu is one of the feasible locations for installation of wind farms, these results will serve as a tool for decision makers to choose the right combination of RE sources to meet the target of 58.7GW from renewable sources by the year 2030. For wind projects to be successful in the kingdom, and to allow competitiveness in the RE sector, there is need for the government to appraise the regulatory and legal framework that will permit the public/private partnership.

Table 2. Techno-economic analysis of selected wind turbines

| Model | No of Wind Turbines | Hub Height (m) | Rated Capacity (MW) | Initial Capital Cost (10 ⁶ \$) | Operating Cost (\$/Year) | Net Present Cost (\$) | LCOE (\$/kWh) |
|-------------------|---------------------|----------------|---------------------|---|--------------------------|-----------------------|---------------|
| Vestas V82 | 5 | 70 | 1.65 | 22.5 | 511,505 | 30.3 | 0.113 |
| Vestas V47 | 15 | 50 | 0.6 | 25.8 | 585,545 | 34.8 | 0.129 |
| Enercon E-82 E4 | 4 | 84 | 4 | 24.2 | 509,662 | 32.0 | 0.119 |
| EWT DW 52 | 12 | 40 | 0.9 | 26.6 | 592,111 | 35.6 | 0.132 |
| Windflow 45 | 23 | 38 | 0.5 | 28.4 | 637,810 | 38.1 | 0.142 |
| Leitwind 90 | 4 | 97.5 | 2 | 18.6 | 406,168 | 28.4 | 0.0921 |
| Enercon E-126 EP4 | 2 | 135 | 4.2 | 17.9 | 383,086 | 23.8 | 0.0885 |
| Vergnet GEV MP-C | 35 | 55 | 0.275 | 27.3 | 637,970 | 37.0 | 0.138 |
| WES 30 | 43 | 48 | 0.250 | 28.3 | 655,120 | 38.3 | 0.142 |
| XANT L-33 | 24 | 55 | 0.330 | 24.4 | 574,409 | 33.1 | 0.123 |

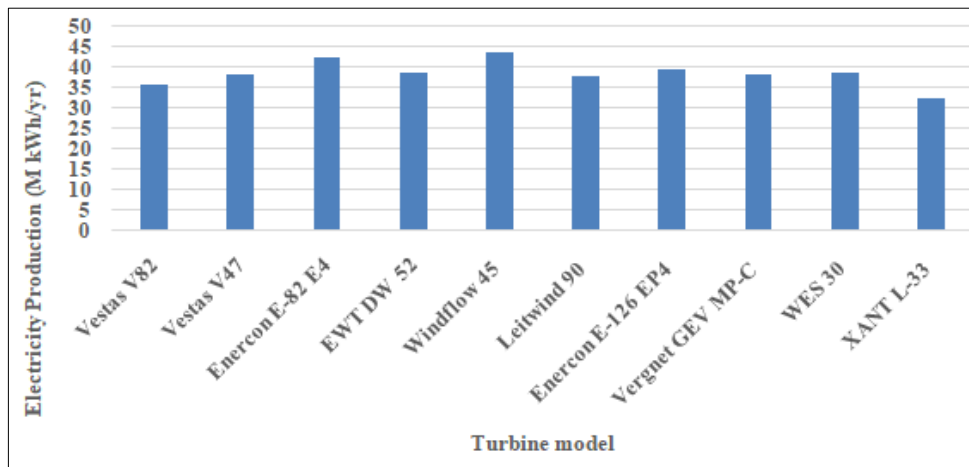


Figure 4. Electricity production from each of the wind turbines per year

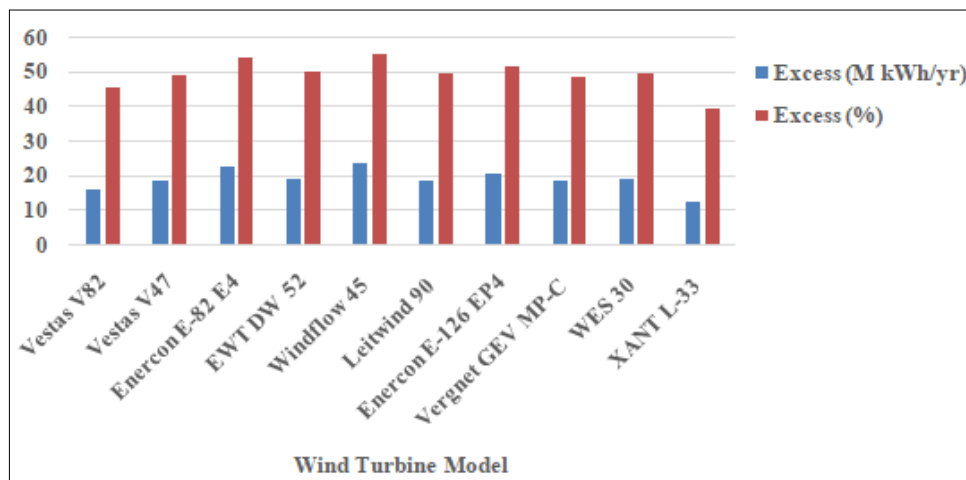


Figure 5. Excess energy and its percentage for each wind turbine

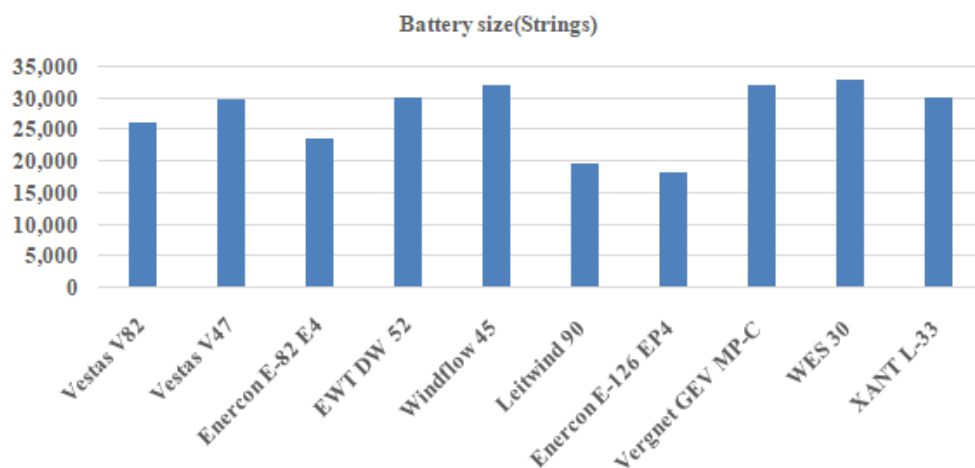


Figure 6. Battery size in strings required for each wind turbine

6. CONCLUSION

In this paper, the possibility of utilizing wind energy as an alternative source to meet the energy demand of a village in the Yanbu region of Saudi Arabia was explored. Simulations were carried out using HOMER software. Ten types wind turbines with a lifetime of 25 years were evaluated for installation in Yanbu. These wind turbines were chosen among the commonly available types of wind turbines deployed for projects across the globe. In this paper, the LCOE value was used as the main parameter to choose the optimal wind turbine. The results show that Enercon E-126 EP4 is the optimal wind turbine for the area with the lowest LCOE (i.e. 0.0885 \$/kWh), while the highest LCOE appears to be with the WES 30 wind turbine (i.e. 0.142 \$/kWh). In future studies, additional selection criteria such as space required for a wind turbine and cost of the land may be considered.

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