The Potential of Wind for Energy Production and Water Pumping in Iran, Saravan County

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ABSTRACT

Sustainable sources of energy are vital for energy production in remote areas which have difficult access to electricity and grid. Thus, in this paper an initial evaluation of wind resource for over 18 months was done to evaluate the potential of wind energy as a power generation source in a remote village in Saravan county, southeastern Iran. The Weibull distribution is employed to model the wind data at three heights: 10, 30 and 40 meters. The Weibull distribution presented in this study indicates a good compatibility with the measured wind data. Different wind speed parameters such as monthly and diurnal wind speed profiles at different heights, wind direction, turbulence intensity, and etc. have been estimated and analyzed. The results showed the studied site has not the sufficient wind speed and power for development of commercial wind power plants. But the studied site may be suitable for development of small and residential wind turbines. Therefore in the next part of study, energy production of different small wind turbines has been estimated. It was concluded that one of the small wind turbines which has the highest net energy production of 33,685 kWh/yr and highest capacity factor of 25.6% can be suitable for non-grid connected electrical and mechanical applications, such as local consumption, battery charging, and water pumping. In the last phase of study, the water pumping potential of the studied area has been investigated.

Key words: Iran, residential wind turbine, Saravan county, water pumping, wind energy, Weibull distribution

INTRODUCTION

The increasing demand of energy, growing environmental concerns and rapidly depleting reserves of fossil fuels have made planners and policy makers think and search for ways to supplement the energy base with renewable energy sources. Wind energy is among the potential alternatives of renewable clean energy to substitute for fossil fuel-based energy sources, which contaminate the lower layers of the troposphere. Because of its cleanness, wind power is sought wherever possible for conversion to electricity with the hope that air pollution will be reduced as a result of less fossil fuel burning.

The power of wind has been utilized for thousands of years. The old applications of wind energy are extracting water from wells, making flour out of grain and other agricultural applications. Recently, the use of wind energy has evolved to, mainly, generation of electricity. The field of wind energy blossomed in 1970s after the oil crisis, with a large infusion of research money in the United States, Denmark, and Germany to find alternative sources of energy. By the early 1980s, incentives for renewable sources of energy had vanished in the United States and, therefore, the wind energy field shrank significantly. Investments continued in Europe and, until recently, Europe led in terms of technology and wind capacity installations [1].

In 2011 among 98 countries using wind energy Iran was ranked 43rd. And unfortunately Iran's position in 2012 was increased to 47th [2]. This means that although Iran has a favorable wind resource, the use of wind energy in this country is too limited. Although there are several companies attempting to establish wind power plants in different districts in Iran, it cannot be said that the work in this field is satisfactory. Much more is needed to be done to increase interest and investment in this subject.

The wind characterization in terms of speed, direction and wind power is the first step to obtain the initial feasibility of generating electricity from wind power through a wind farm, in a given region [3-7]. Wind resource assessment has been done in 68 sites all over Iran using geographic information system [8], including locations such as Hormozgan province [1], Abadan [3 Shahrbabak [9], Esfehan province [10], Yazd province [11], Semnan province [12] and Tehran, the capital of Iran [13].

PROBLEM DESCRIPTION AND AIM

In the current research, the meteorological mast (which contains wind data) is located in a remote village which is in Saravan county in Sistan and Baluchestan province. According to a report published on July 2014 by official website of Tabnak Iranian news and many other news centers in Iran [14-17], people of the studied village in Saravan county have many difficulties to access water supply. In fact they have access to drinking water only half an hour per week which is a disastrous problem. Irrigation in this village which is already done by water tanks cannot meet the water demand for the people. Thus many of these people are oriented towards extracting water from wells. News has reported the difficulty in accessing water has caused people to fight each other. So far four individuals have been killed because of this issue. Furthermore, this village is a low-populated and remote location with no connection to the grid and difficult access to the electricity, leading to poor standards of living. All of these facts still did not catch the attention of the related organizations to solve these problems with regard to water supply and electricity.

The aim of this study is to evaluate the use of wind energy as a power generation source and also for water pumping in the studied site. In the next parts, the wind data of the studied site is processed to assess the regional wind power potential.

MATERIAL AND METHODS

Weibull Distribution Function

Weibull distribution function is named after Waloddi Weibull in 1951 and has widely been used for characterizing wind regimes. The wind speed probability density function can be calculated as Eq.1 [1]:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{1}$$

Where f (v) is the probability density function (pdf) of observing wind speed v, c is the Weibull scale parameter and k is the dimensionless Weibull shape parameter [1, 18].

Wind Power Density

Wind power density (WPD, watts/m^2) is defined as the wind power available per unit area swept by the turbine blades and is given by the Eq. 2 [2]:

$$WPD = \frac{1}{2n}\sum_{i=1}^{n} \rho(v_i^3) \tag{2}$$

Where n is number of records in the averaging interval, ρ is air density, v_i^3 is cube of the ith wind speed value [2]. Besides, calculation of wind power density (P/A, watts/m^2) based on the measured wind speed can be developed by Weibull distribution analysis using the following form [2]:

$$\frac{P}{A} = \int_0^{\infty} \frac{1}{2}\rho U^3 f(U)dU = \frac{1}{2}\rho c^3 \Gamma\left(\frac{k+3}{k}\right) \tag{3}$$

Where U is the mean wind speed and A is blade sweep area. The gamma function of (x) (standard formula) is calculated as Eq. 4 [1]:

$$\Gamma(x) = \int_0^{\infty} e^{-u} u^{x-1} du \tag{4}$$

ANALYSIS OF RESULTS

Ten-minute time interval wind data have been extracted during 18 months from 2006 to 2007 from a meteorological mast located in a remote village (27.14368 N 62.67179 E) in Saravan county in Sistan and Baluchestan province in southeast of Iran [19, 20]. The data was analyzed by Windographer software [21]. The average temperature and relative humidity in the studied site are calculated to be 20.4°C and 24.1%. The meteorological masts with 40 m height were installed in suitable coordinates by the power ministry. The data logger used has three sensors of velocity at 10 m, 30 m and 40 m heights and also two sensors of direction at 30 m and 37.5 m. Figure 1 demonstrates the position of studied site in Iran using Google earth [22].

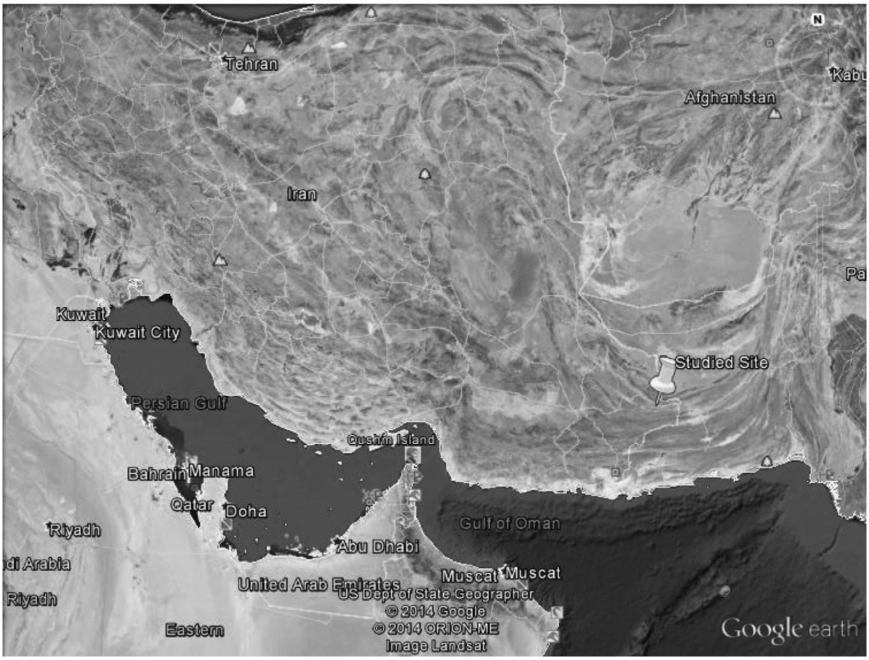


Figure 1. The position of studied site in Iran is shown with the help of Google earth [22].

Analysis of Wind Speed Characteristics

In Table 1, initial information about wind speed characteristics is given. According to a basic classification of wind speeds which is provided in Table 5 of Ref. [23], and by inspecting Table 1, it can be found that at height of 10 m the wind potential is poor and at heights of 30 m and 40 m the wind potential is marginal. In general it can be concluded that the studied site doesn't have sufficient wind potential for development of commercial wind turbines (required WPD ≥ 200 W/m^2). But the studied site can be suitable for development of small and residential wind turbines. Therefore in the next parts of this study, feasibility study of installing small wind turbines (for residential use) is considered.

Monthly mean wind speeds at heights of 10 m, 30 m and 40 m are plotted in Figure 2. It can be seen that wind speed patterns at 30 m and 40 m heights are similar to each other but at 10 m the wind pattern is a little different. By looking at Figure 2 it is clear that at three heights

Table 1. Calculated wind speed parameters in the studied site.

Height (m)	10 m	30 m	40 m
Mean wind speed (m/s)	3.05	4.164	4.40
Gust wind speed (m/s)	26 (21/6/2007 15:55)	25.6 (21/6/2007 15:45)	26 (21/6/2007 15:45)
Weibull distribution coefficients	k=0.84 c=2.84 m/s	k=1.40 c=4.57 m/s	k=1.44 c=4.85 m/s
Wind power density (W/m^2)	78.61	131.19	150

monthly mean wind speeds are ranged from 1.9 m/s in Aug to 5.9 m/s in May. In the months of May at 30 m and 40 m heights, the mean wind speed is over5.5 m/s and therefore more wind energy can be harnessed by wind turbines.

In the Table 1, the gust wind speed values are the maximum instantaneous wind speed values occurred in the studied site during 18 months of the recorded wind data. As it can be observed from Table 1 at height of 40 m the gust wind speed value is 26 m/s (this is not relatively high) and occurred at 21/6/2007 15:45. Extreme wind conditions, such as wind gusts and/or wind direction changes, can lead to very large turbine loads causing fatigue, automatic shut-downs or even damage to some turbine components [5].

In wind data analysis, the prediction of the wind direction is very important, especially in the time of planning the installation and the micro-siting of a wind turbine or a wind farm. A wind rose is a convenient tool for displaying the direction of the wind for siting analysis [6]. Figure 3 demonstrates the monthly prevailing wind direction in the studied site. As it can be inferred from this figure, in the months of Jan, May, Jul, Aug, Sep and Oct the prevailing wind direction is mostly from north-east but in the months of Feb, Mar, Apr and Nov the wind direction appears to be mostly from west.

Figure 4 shows a single wind rose (which is plotted for one year) at heights of 30 m and 37.5 m for the studied region. As a result it can be concluded that mostly prevailing winds are from west and northeast.

Wind speed frequency distributions at heights of 10 m, 30 m and 40 m have been estimated using Weibull probability function. Inspect-

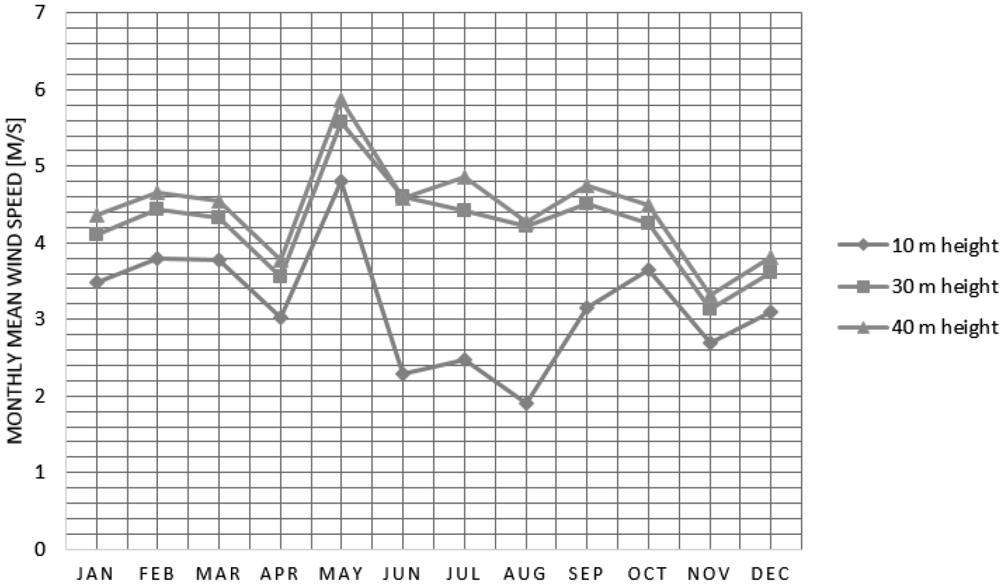


Figure 2. Monthly wind speed profile in studied site.

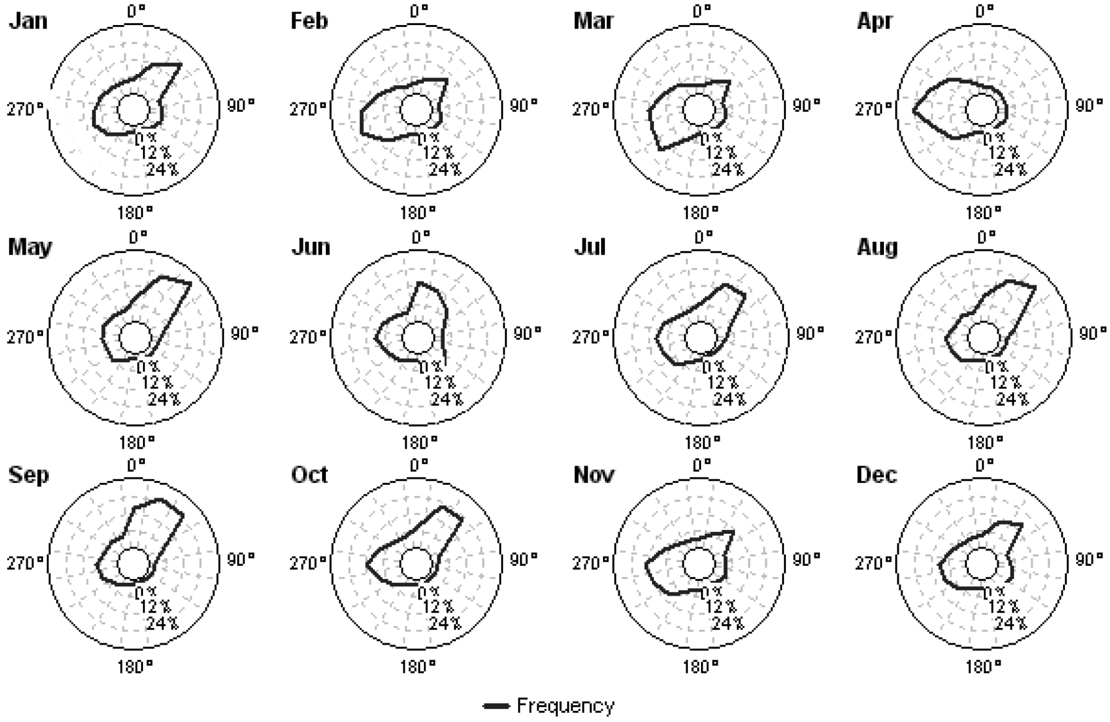


Figure 3. The monthly direction of wind in Saravan county.

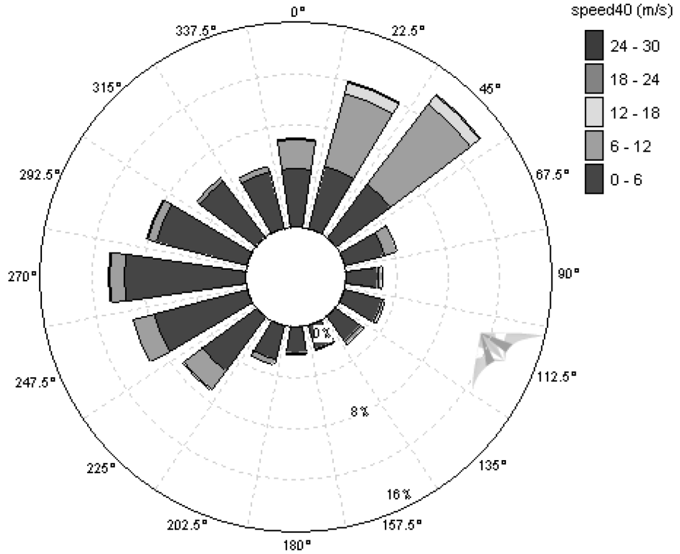


Figure 4. Annual wind rose in the studied village.

ing the graphical result in Figure 5, it can be seen that the Weibull distribution (at 40 m height) fits the measured data very well. Shape (k) and scale (c) values of the Weibull function were calculated and they can be seen in Figure 5 for 40 m height.

In the field of wind resource assessment one of the most important parameters is the turbulence intensity. Turbulence intensity quantifies how much the wind varies typically within a 10-minute period. Because the fatigue loads of a number of major components in a wind turbine are mainly caused by turbulence, the knowledge of the site's turbulence is crucial [1]. In this study the diagram of annual turbulence intensity (TI) for each month is plotted in Figure 6. In the last column of this diagram in Figure 6 which is denoted by "A," the annual values of TI are shown. High values of turbulence intensity which are more than 12 at height of 40 m occurred in Feb, Mar, Jun, July, Sep and Dec. The mean maximum value of TI in all over the year was observed in Jun with value of almost 15 which is a little high. Apparently high values of turbulence intensity at 40 m height can be a negative factor for choosing Saravan County as a suitable place for installation of wind turbines. Therefore to solve this problem, in the next graph in Figure 7, the wind turbulence intensity at 40 m height was shown by a polar diagram. This graph is useful to determine the direction of wind in which it has the

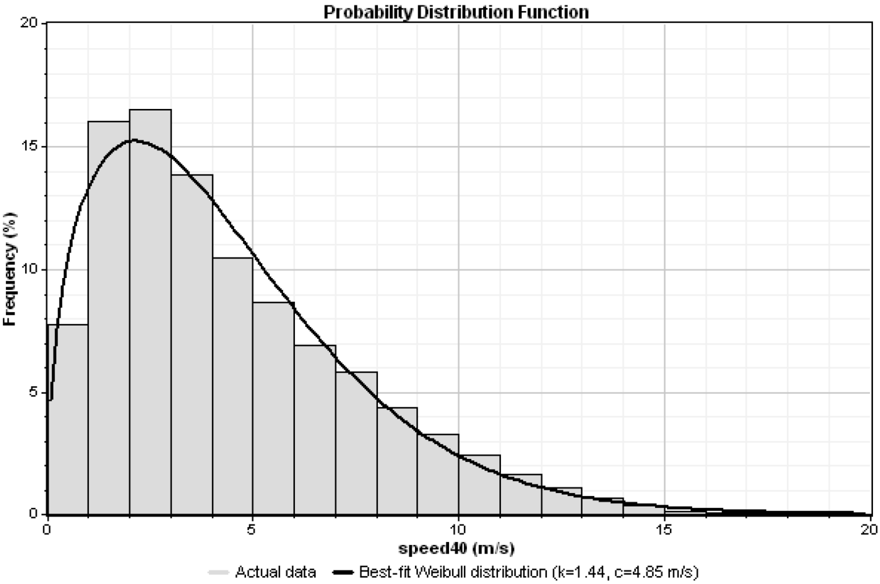


Figure 5.Wind speed distribution at 40 m.

highest wind turbulence intensity. On the one hand, in order to minimize fatigue loads on the wind turbine caused by turbulence intensity and on the other hand to obtain the maximum power of the wind, wind turbine orientation should be aligned according to the polar diagram of turbulence intensity in Figure 7 and the wind rose in Figure 4. As it can be observed from the Figure 7, the direction sector of 180°C has the maximum TI among all of the directions. It can also be inferred from this figure that the prevailing wind turbulence intensity is mostly from south and south east.

Wind Turbine Energy Production

Since, in the first phase of study (according to Table 1 and Figure 2) it was concluded that the wind potential of the area is not suitable for power production in large-scale, thus in this part of study energy production of four small wind turbines has been estimated. The power curves of these small wind turbines are depicted in the Figure 8. As it can be seen, among all of the studied small wind turbines, power curve of the turbine "proven 15" (which is shown with green color) is showing a better ability of this turbine for power production compared to other wind turbines.

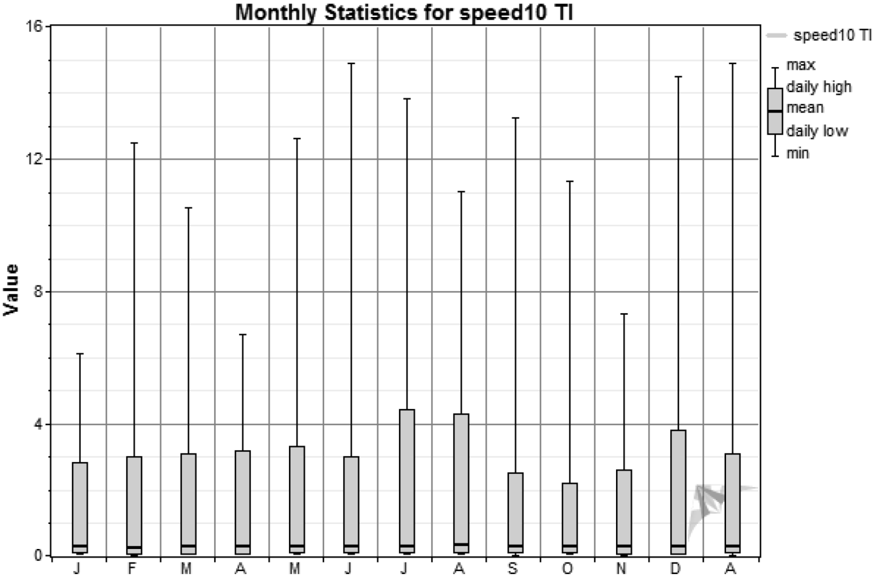


Figure 6. Monthly mean turbulence intensity at 40 m.

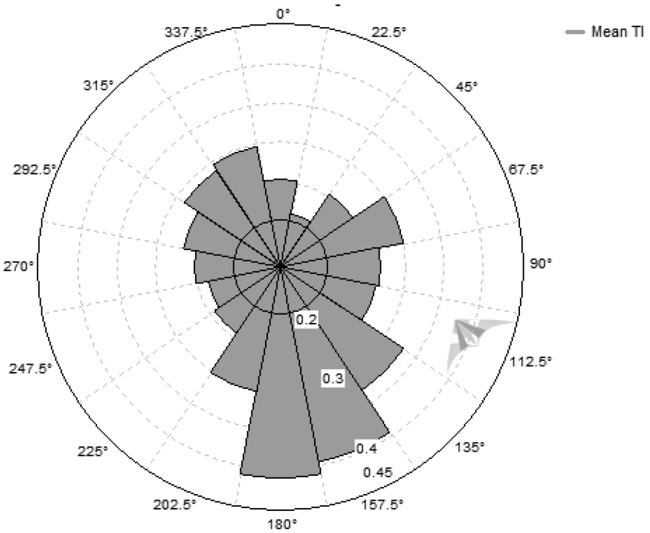


Figure 7. Polar diagram of turbulence intensity at 40 m height.

In the Table 2, energy production, hub-height wind speed and capacity factor of four small wind turbines have been calculated. For calculation of power production, the overall loss factor was considered 16%. As it can be seen the "proven 15 kW" with hub-height of 40 meters has the highest energy production and capacity factor of 33,685 kWh/yr and 25.64% respectively. The capacity factor is the most effective parameter which indicates the power generation efficiency of the wind energy generator and also it will have direct effect on cost of electricity. It is an indicator of economic viability of any wind power project. It may be noted that the usual capacity factor for a wind turbine or a wind farm should be something around 20 – 40% [1, 24].

Another parameter seen in Table 2 is the percentage of the time at which the wind turbine is operating at its rated power. It clearly can be seen that the "Proven 15 kW" has the highest rate which is 6.48%. In general, it can be concluded that among all studied small wind turbines in this paper, the "Proven 15" with rated power of 15 kW and hub-height of 40 m can be utilized for energy production. In the next section, the potential of water pumping of the studied area has been investigated using a small wind turbine.

Water Pumping Potential in the Studied Village

In the last part of this study, for the first time in Saravan County, an effort has been made to utilize power of the wind for pumping the water for remotely located inhabitants not connected with national power grid. Figure 9 illustrates schematic layout of a village water supply system showing the five major components: water pumper, water source, storage tank, water stand point and power source from a small wind turbine [25]. In this case, we consider only the 15kW small wind turbine from Proven Energy due to its highest capacity factor (25.6%), highest net annual energy production (33,685 kWh/yr) and also the highest percentage of time working at rated power (6.48%). In this study a type of Gould submersible pump (with motor size of 3 horsepower and model of 45 J series) [26, 27], has been used to exploit the energy generated by the wind turbine for pumping underground water. The 45 J series of Gould Pump Company (used for 6" and larger wells) which are mainly designed for municipal and agricultural water needs, have the benefit of operating continuously without motor damage. Figure 10 shows a typical 45 J pump produced by Gould pump company with its structure.

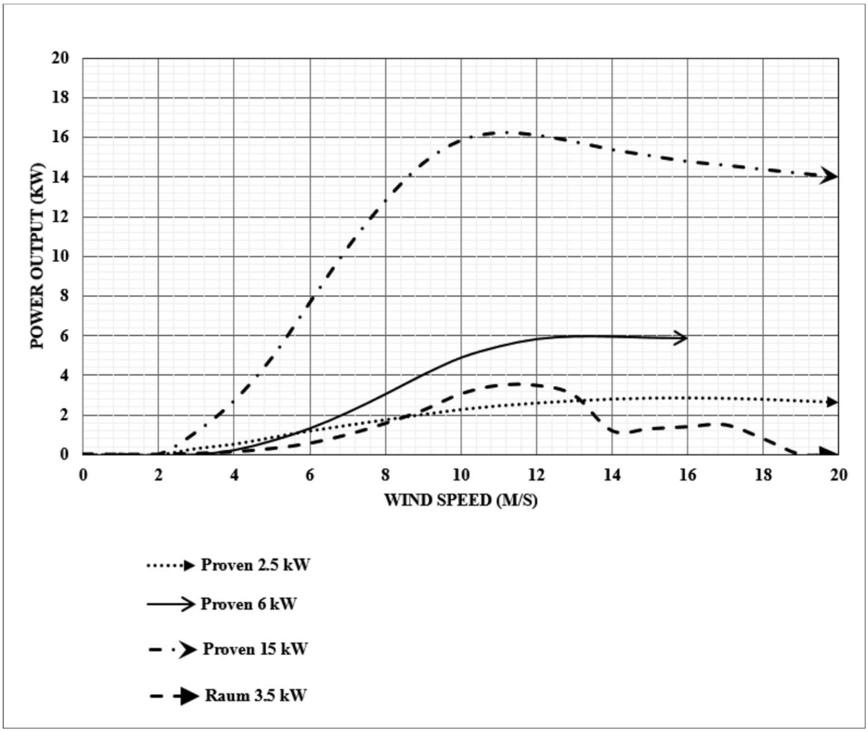


Figure 8. The power curves of four studied small wind turbines [21].

Table 2. Energy production, hub-height wind speed and capacity factor of four small wind turbines used in the studied site.

Turbine (with rated power & hub-height)	Hub Height Wind Speed (m/s)	Net Annual Energy Production (kWh/yr)	Net Capacity Factor (%)	Percentage Of Time At	
				Zero Power	Rated Power
Proven 15 kW (40m)	4.4	33,685	25.64	25.46	6.48
Proven 2.5 kW (10m)	3.05	3,516	16.05	45.7	0.85
Proven 6 kW (10m)	3.05	4,531	8.62	45.74	0.02
Raum 3.5 kW (10m)	3.05	2,420	7.89	15.76	0.09

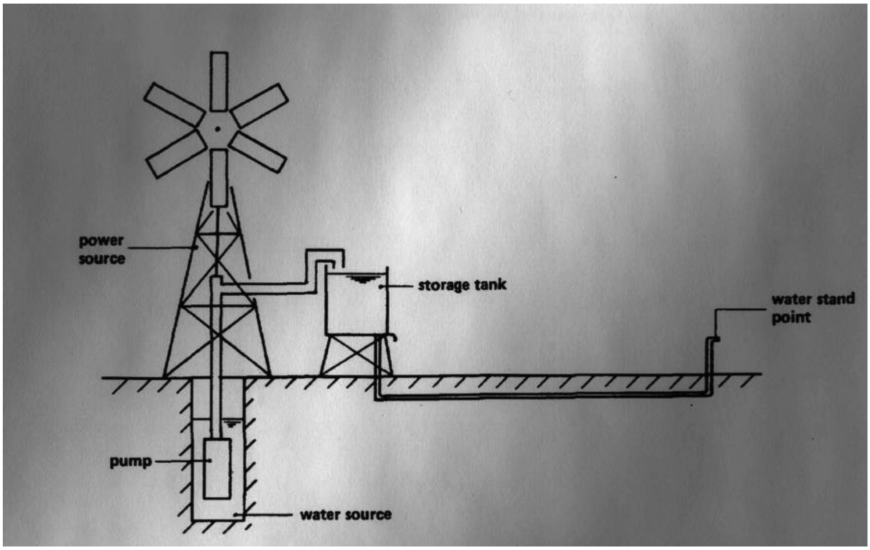
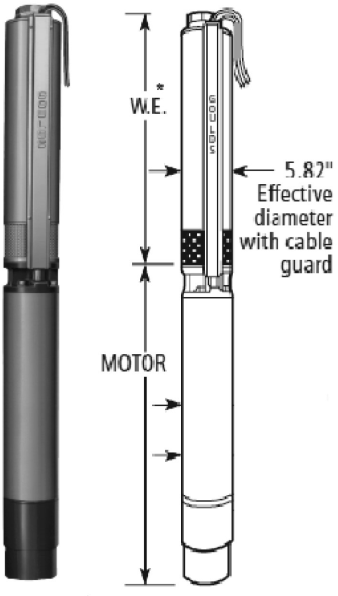


Figure 9. Schematic layout of a village water supply system showing the five major components [25].



* W.E= Water End

Figure 10. Schematic layout a 45 J pump produced by Gould pump company [26, 27].

According to a research published by Hindawi Corporation [28], these pumps yield 227.87 m4 of pumping capacity per kWh energy and therefore their water pumping capacity rate can be expressed as Eq.5 [28]:

$$\text{Flow capacity rate } (m^4/hr) = 227.87 \times \text{Power (kW)} \tag{5}$$

If we consider the total dynamic head (TDH) of 50 m, then the volumetric yield of these pumps is obtained to be 227.87/50 = 4.56 m^3 per kWh energy. Table 3 demonstrates monthly energy yield of Proven (15 kW) wind turbine at height of 40 m and corresponding monthly total water pumping capacities using Goulds 45 J series of submersible pumps for a total dynamic head (TDH) of 50 m.

As it can be inferred from the Table 3, monthly water pumping capacities at 40 m height are ranged from minimum of 8,908.55 m^3 in Apr to maximum of 27,840.48 m^3 in Sep with annual value of 221,644.91 m^3/yr. This corresponds to daily average of 297-928 m^3 of water pumping capacity at 40 m height. At 20 m height, the minimum and maximum water pumping capacities were found to be 7,727.74 and 25,762.17 m^3 respectively. The annual value at 20 m was calculated 204,065.38 m^3. As it can also be noted from the Table 3, an increase in the water pumping capacity is seen as the hub height increases from 20 m to 40 m. Also in general it can be concluded that compared to a research that dealt with utilizing the power of the wind by small wind turbines for water pumping potential of Suaudi Arabia [29], there is good potential of water pumping in the studied site. Especially in Sep—which is considered as summer and in this month compared to other months of the year the demand for water is usually higher for irrigation purposes—the maximum water pumping capacity has been observed.

CONCLUSION

In this study, wind data at different heights in the time interval of 10 minutes was analyzed to determine the potential of the wind in Saravan county in Iran based on Weibull probability distribution function. It was concluded that the Weibull distribution presented in this paper indicates a good agreement with the data obtained from actual measurements. Furthermore, at three heights of 10 m, 30 m and 40 m

Table 3. monthly energy yield of Proven (15 kW) wind turbine at height of 40 m and corresponding monthly total water pumping capacities using Goulds 45 J series of submersible pumps for a total dynamic head (TDH) of 50 m.

Month	Hub height of 40 (m)		Hub height of 20 (m)	
	kWh energy production	Capacity of water pumping (m^3)	kWh energy production	Capacity of water pumping (m^3)
Jan	2,991.08	13,639.32	2,692.83	12,279.30
Feb	2,803.88	12,785.69	2,551.22	11,633.56
Mar	3,033.8	13,834.12	2,772.36	12,641.96
Apr	1,953.63	8,908.55	1,694.68	7,727.74
May	4,086.12	18,632.70	3,815.62	17,399.22
Jun	5,027.66	22,926.12	4,745.22	21,638.20
July	5,052.90	23,041.22	4,813.45	21,949.33
Aug	5,192.17	23,676.29	4,923.27	22,450.11
Sep	6,105.37	27,840.48	5,649.60	25,762.17
Oct	5,714.71	26,059.07	5,194.38	23,686.37
Nov	3,492.53	15,925.93	3,094.64	14,111.55
Dec	3,153.32	14,379.13	2,804.18	12,787.06
Annual	48,606.34	221,644.91	44,751.18	204,065.38

monthly mean wind speeds are ranged from 1.9 m/s in Aug to 5.9 m/s in May. In the month of May at 30 m and 40 m heights, the mean wind speed is upper than 5.5 m/s and therefore more wind energy can be captured by wind turbines. The wind rose analysis showed that, prevailing wind directions are from west and northeast. Also it was found that the mean power densities are calculated 78.61 w/m^2, 131.19 W/m^2 and 150 W/m^2 for 10 m, 30 m and 40 m heights respectively. As a result, eighteen months study of wind data in Saravan county in south east of Iran has showed that at height of 10 m the wind potential is weak but at heights of 30 and 40 m the wind potential is marginal. In general it was concluded that the studied site doesn't have sufficient wind potential for development of commercial wind turbines but it may has enough wind potential for installation of small and residential wind turbines. Thus, a feasibility study of installing small wind turbines (for residential use) was considered. The result showed that one of the small wind turbines which has the highest net energy production of 33,685 kWh/yr and highest capacity factor of 25.6% can be suitable for development of non-grid connected electrical and mechanical applications, such as local consumption, battery charging, and water pumping. In the last part of study the water pumping potential of the studied site has been investigated. It became clear that, by considering a total dynamic head (TDH) of 50 m, monthly water pumping capacities at 40 m height are ranged from minimum of 8,908.55 m^3 in Apr to maximum of 27,840.48 m^3 in Sep with annual value of 221,644.91 m^3/yr while at 20 m height the minimum and maximum water pumping capacities were found to be 7,727.74 and 25,762.17 m^3 respectively. The annual value at 20 m was calculated 204,065.38 m^3. On the whole it was concluded that by using small-scale wind turbines, there is a good potential of water pumping capacity in the studied site.

In recent years the development of hybrid renewable energy systems in remote areas with difficult access to grid has become an important issue due to advances in renewable energy technologies, subsequent rise in prices of petroleum products and increase in the environmental pollutions caused by fossil fuels. Therefore the next part of this research aims to deal with design and utilization of optimized hybrid renewable energy systems in remote areas in Saravan County in south east of Iran for the purpose of energy production and water pumping.

Acknowledgment

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