



Wind power utilization for water pumping using small wind turbines in Saudi Arabia: A techno-economical review

Shafiqur Rehman^{a,*}, Ahmet Z. Sahin^b

^a Center for Engineering Research, King Fahd University of Petroleum and Minerals, KFUPM Box 767, Dhahran 31261, Saudi Arabia

^b Department of Mechanical Engineering, King Fahd University of Petroleum and Minerals, Dhahran 31261, Saudi Arabia

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ABSTRACT

An attempt has been made, may be first time in Saudi Arabia, to utilize power of the wind for pumping the water for remotely located inhabitants not connected with national power grid. Small turbines of 1–10 kW have been chosen in conjunction with Goulds 45 J model water pumps to produce energy from wind and pump water using the produced energy at Arar, Rawdat Ben Habbas and Juaymah localities in Saudi Arabia. Wind speed measurements made at different heights using 40 m tall towers have been utilized in the present work. Higher wind speeds were noticed during summer time compared to winter time at all the locations. Both energy yield and cost of energy point of view, 2.5 kW wind turbine from Proven was found to be most suitable for wind power generation at all sites. It is shown that annual total water pumping capacity of 30,000 m³ is possible from a depth of total dynamic head of 50 m when using 2.5 kW Proven wind turbine with hub heights 15–40 m at all three sites with cost of water pumping as low as 1.28 US¢/m³.

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Contents

1. Introduction	4470
2. Site and data description	4471
3. Wind speed and plant capacity factor analysis	4471
4. Wind energy estimation	4472
5. Estimation of cost of wind energy (COE)	4474
6. Water pumping potential	4475
7. Conclusions	4477
Acknowledgment	4478
References	4478

1. Introduction

Water accessibility and availability are the key issues arising in densely populated cities in developed and developing countries and Saudi Arabia is not an exception. Having vast land, the populations are scattered and located primarily in some major cities but largely in remote areas. Transportation of water to all of these localities is difficult to maintain continuously, especially

remote locations in mountainous regions. Saudi Arabia is blessed with lot of wind resources in coastal areas and mountainous regions and hence encouraged to be utilized for water pumping. Power of the wind is a clean, inexhaustible, free, reliable, and renewable source of energy. To further add to its advantages, it is quick to install, require negligible maintenance, and it does have any political or geographical boundaries. Power of the wind has become the power technology of choice for a number of countries around the globe. According to Global Wind Energy Council Report [1], the world's wind power capacity grew by 22.5% in 2010, adding 35,802 MW to bring total installations to 194,390 MW. Almost one half of these additions were made in China, which experienced yet another year of approximately 65%

* Corresponding author. Tel.: +966 3 8603802, mobile: +966 502085496; fax: +966 3 8603996.

E-mail address: srehman@kfupm.edu.sa (S. Rehman).

growth. Newly added capacity of 2139 MW in India and some smaller additions in Japan, South Korea and Taiwan make Asia the biggest regional market for wind energy in 2010, with more than 19,022 MW of new capacity.

As a source of power, wind has been used for over 2000 years [2]. The wind power pumping applications are well known and include community and domestic water supply, cattle watering, irrigation, drainage and salt pans, Smulders [3]. Roughly the water head required for community, domestic and cattle watering varies from medium (10–30 m) and deep (> 30 m) and for remaining categories very low (3 m) and low (3–10 m). Back in 1986 and 1994, Smulders [4] and Smulders and de Jongh [5] presented the review of the state of the art in the field of wind pumping, its applications, economics and potential. Water pumping has been one of the main applications for wind power and there are more than a million wind pumps in regular use [6]. Small wind-electric systems have become quite popular [7] these days for pumping water from underground or lifting to tanks located high up due to greater flexibility over mechanical systems [8] and being able to spare electricity for other usages. Bowen et al. [9] reported practical experience related to 10 kW Bergey wind-electric hybrid power system operated in conjunction with a diesel back-up generator and found that the actual performance differed significantly from the manufacturer's data, partly due to furling in variable conditions [9].

Study related to possibilities of using wind energy for pumping water in various localities of Jordan was reported by Mohsen and Akash [10]. The results showed that power of the wind could be utilized at most of the eleven sites studied to pump groundwater in Jordan. Al-Suleimani and Rao [11] investigated the performance of a pump at different wind speeds and monthly water output against average wind speed and compared the outcome with the design values provided by the manufacturer. Authors concluded that wind energy can be used successfully to pump the groundwater in remote locations in Oman with adequate wind resources available. Bouzidi [12] reported utilization of wind energy resources for pumping the water in Adrar region of Algeria. They showed that wind power pumping system is viable both technically and economically in Adrar region compared to solar PV based water pumping system. Hammad [13] showed that mechanical photovoltaic wind pumping systems were economically cheaper than the diesel based water pumping system in Jordan.

Harries [14] presented a historical review of the design, field-testing and manufacturing experiences of BHEL in the development of wind pumps for water pumping in remote rural areas. The study outlined the challenges facing the dissemination of wind pumps in Africa and its benefits to rural and remote communities. Bragg and Schmidt [15] presented a procedure for optimum selection of pumps and windmills for a given water pumping situation. With information available on the wind intensity, pump and wind turbine characteristics, the best pump and turbine could be selected for the application. Previous works

on the matching of pumps and windmills have been reported by Vadot [16] and Banas and Sullivan [17].

In Saudi Arabia, lot of work has been done on wind power resources assessment, hybrid power system design, wind measurements, and grid connected wind farm design as can be seen from references [18–26]. The present study proposes the utilization of wind power for water pumping in Saudi Arabia using wind speed data measured at different heights using 40 m tall towers.

2. Site and data description

The present work utilized wind speed data measured at 20, 30 and 40 m above ground level for a period of two to four years at Arar [27], Rawdat Ben Habbas [24] and Juaymah [23]. The site dependent details and data measurement periods are given in Table 1. At each height two sensors were installed and data was scanned every 3 s and was recorded every 10 min. The surface air temperature (°C), relative humidity (%), surface station pressure (in. of Hg), and global solar radiation (W/m²) data was collected at 1.5 m above the ground surface. The operating ranges and accuracies of various sensors used for the measurements are given in Table 2. The data collection site at Rawdat Ben Habbas was an open area from all directions except a couple of warehouse shades and diesel storage tanks in the far vicinity of wind mast. The area around the wind mast in Juaymah was surrounded by government and private industries and power plants which are connected to the national electric grid. The Arar meteorological data measurement site was an open area from all directions. The land surface was comprised of small rocks.

3. Wind speed and plant capacity factor analysis

The wind measurements are usually made at 5–10 m above ground level then are extrapolated to higher heights using wind power law which provides a rough estimate of the wind speed and hence the wind energy. The annual mean wind speeds measured at different heights along with other relevant meteorological parameters (temperature-T, pressure-P, and relative humidity-RH) is summarized in Table 3. It is evident from this table that wind speed increases with height at all the stations. Annual variation of wind speed provides an insight into the availability and intensity of the wind during different years, which, in turn, facilitates the estimation of energy yield from the wind turbines or wind farms in the vicinity of the measurements. The annual trends of the wind speed also provide information about the increase or decrease in annual mean wind speed with upcoming years. In the present case, the annual mean wind speeds were calculated for complete years, which mean that the years with missing values even for five days were not considered in the analysis.

The annual mean wind speed variation over the data collection period from 2006 to 2009 at Rawdat Ben Habbas is shown in Fig. 1. The annual mean wind speed was observed to increase by 3% in 2007 compared with that in 2006 but decreased by 3%, 4%, and 1% in 2008 compared with that in 2007 at 20, 30 and 40 m measurement heights, respectively. With respect to height, the annual mean wind speed increased by 13.1% and 6.3% at 30 m and 40 m AGL compared with that at 20 m and 30 m respectively. At Juaymah, the wind speed data was available for only two complete years, namely 2007 and 2008, as shown in Fig. 2. As seen from this figure, the annual mean wind speed increased from 4.13 m/s to 4.81 m/s (16.6%) due to increase in measurement height from 10 m to 20 m. Similarly, an increase of 10.3% and 6.6% was noticed in annual mean wind speed values at 30 and 40 m

Table 1
Site specific information of 40 m tall towers.

Location	Latitude (°N)	Longitude (°E)	Altitude (m)	Data period
Rawdat Ben Habbas	29.14	44.33	443	Sep. 2005 to Apr. 2010
Juaymah	26.80	49.90	20	Jul. 2006 to Apr. 2009
Arar	30.80	41.30	550	Jun. 1995 to Dec. 1998

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