Wind Mechanical Engineering: Energy for Water Pumping in Rural Areas in Sudan

A. M. Omer*

*Energy Research Institute (ERI),

Forest Road West, Nottingham NG7 4EU, United Kingdom, abdeenomer2@yahoo.co.uk

ABSTRACT

The imminent exhaustion of fossil energy resources and the increasing demand for energy were the motives for those reasonable in Sudan to put into practice an energy policy based on rational use of energy; and on exploitation of new, and renewable energy sources. After 1980, as the supply of conventional energy has not been able to follow the tremendous increase of the production demand in rural areas of Sudan, a renewed interest for the application of wind energy has shown in many places. Therefore, the Sudanese government began to pay more attention to wind energy utilisation in rural areas. Because the wind energy resource in many rural areas is sufficient for attractive application of wind pumps, and as fuel is insufficient, the wind pumps will be spread on a rather large scale in the near future. Wind is a form of renewable energy, which is always in a non-steady state due to the wide temporal and spatial variations of wind velocity. A number of years worth of data concerning wind speed in Sudan have been compiled, evaluated and presented in this article. The need for the provision of new data stations in order to enable a complete and reliable assessment of the overall wind power potential of the country is identified and specific locations suggested. This paper presents the background and ideas of the development of the concept as well as the main results, and experience gained during ongoing project up to now. In Sudan, various designs of wind machines for water pumping have been developed and some designs are presently manufactured commercially. Results suggest that wind power would be more profitably used for local and small-scale applications especially for remote rural areas. It is concluded that Sudan is blessed with abundant wind energy.

Keywords: Sudan, renewable technologies, wind energy, water pumping

1 INTRODUCTION

New and renewable sources of energy can make an increasing contribution to the energy supply mix of the Sudan in view of favourable renewable energy resource endowments, limitations and uncertainties of fossil fuel supplies, adverse balance of payments, and the increasing pressure on environment from conventional energy generation. Among the renewable energy technologies, the generation of mechanical and electrical power by wind machines has emerged as a techno-economical viable and cost-effective option.

The use of wind pumps declined dramatically from the 1920s due to the economic depression and the use of electric motors or petrol and diesel engines to drive water pumps. Soaring energy prices in the 1970s and growing interest in renewable energy sources led to their reconsideration, particularly in Sudan, although the take-up of the technology is still slow. This had led to the following developments:

- The attempts to disseminate wind pumps;
- Adoption of modern engineering analysis and design methods; and
- A new generation of low cost modern wind pumps has evolved but, it has not reached the level of reliability of the old classical wind pumps yet.

The provision of pumped clean water is one of the best ways to improve health and increase the productive capacity of the population. Rural access to clean water is best achieved through pumping from underground water aquifers rather than using surface water sources, which are often polluted. Because of the relatively small quantities of water required, wind pumping for village water supply and livestock watering can is cost-effective given a good wind site. Irrigation pumping, however requires large quantities of water at specific times of the year. For much of the year the pump may be idle or oversized and wind pumping for irrigation may be more difficult to justify on economic grounds.

Wind pumps have been proceeding in Sudan since the 1950s for the purposes of pumping water, for drinking, and irrigation in remote desert areas-Gezira region, the Red sea hills along the main Nile north of Khartoum down to Wadi Halfa. These wind machines are of the Southern Cross types and suffered from several problems. None of them are still working [1]. Since 1975 there has been a revival by incorporating new technologies into the designs (generators, electronics, control systems, etc.). Ten wind pumps types Consultancy Services Wind Energy Developing Countries (CWD)-Holland was installed around the Khartoum area (some of them were working until recently) [2]. The main competitions to wind pumps are diesel pumps sets and solar pumps. Using a diesel engine costs less to buy and easier to site, but requires frequent maintenance, an operator and the diesel fuel. Combining diesel with wind power may bring benefits in some situations. The use of solar energy to power electric pumps has become a reliable and simple technology, and more details are given by Markvart [3]. Solar panels or photovoltaic modules convert the sun's radiation directly into electrical energy to drive the pump set. Solar pumps are expensive to buy initially but require little maintenance and no fuel. As with wind pumping, the relative economics depend on the level of the resource, i.e., and sunlight, at a particular site.

Wind energy is one of the several energy sources alternatives to the conventional primary energy resources, which now power man's industrial and socio-economic activities worldwide. With the notable exception of hydropower (which in fact is renewable) these primary energy resources have definite lifetimes, depending on use rate among several other factors.

The presented work on development of a mechanical wind pump has going on in Sudan for several years. It is based on a multi-bladed rotor with high efficiency. The aim has been to develop a wind pump, which needs limited service, and maintenance; and meets for mass production in Sudan. Wind energy use in Sudan should therefore be directed at slow-running turbines, with attention paid to system reliability, cost reduction and site selection if the tremendous political, social and economic inertia about wind (and other renewable) energy is to be overcome. The market is growing but it relies on a number of small manufacturers, who have limited possibilities and support for research, product and market development [4].

2 WIND ENERGY POTENTIAL

This article sheds light on the possibilities of utilising wind energy in Sudan, and focuses on the viability of manufacturing wind pumps locally. The work is limited to few locations/sites in the country, and results of one reliable site (Soba) have been included in the discussion. Also, the work was limited to one make/type of wind pumps (CWD 5000), but reflections on other makes (Kijito) have been considered. Wind energy for water pumping was the main aim; no other use was included in the research.

Wind flowing around buildings or over very rough surfaces exhibits rapid changes in speed and/or direction, called turbulence. This turbulence decreases the power output of the wind machine and can also lead to unwanted vibrations of the machine. Generally, the effect is stronger when the ridge is rather smooth and not too steep nor too flat. The orientation of the ridge should preferably by perpendicular to the prevailing wind direction. If the ridge is curved it is best if the wind blows in the concave side of the ridge. A quantative indication of acceleration is difficult to give, but increases of 10% to 20% in wind speed are easily attained. Isolated hills give less acceleration than ridges, because the air tends to flow around the hill. This means that in some cases the two hillsides, perpendicular to the prevailing wind, are better locations than top.

The power output of wind rotor increases with the cube of the wind speed. This means that the site for a wind machine must be chosen very carefully to ensure that the location with highest wind speed in the area is selected. The site selection is rather easy in flat terrain but much more complicated in hilly or mountainous terrains. The manipulations are meant to facilitate the judgement to what extent a given location might be suitable for the utilisation of wind energy.

In this respect, interest in the following:

- The daily, monthly and annual wind pattern.
- The duration of low wind speeds and high wind speeds.
- The expected locations must be not too far from the place of measurements.
- The maximum gust speed.
- The wind energy produced per month and per year.

Consideration has been given to the consistent and effective presentation of data. Original data were extracted from published reports by Sudan Metrological Department (SMD) and converted into more useful working units i.e., wind speed in miles per hour to ms^{-1}. 70 stations recorded the relative data available on wind speed and ambient temperature. Wind energy data consists of mean monthly wind speeds and wind directions measured at a height of 10 m above ground from stations throughout Sudan. Relatively accurate and properly maintained anemometers collected data. Vanes and Dines pressure-tube anemographs were used to record hourly mean wind speeds at 23 stations, other stations used beamfort estimates [5]. For most of the stations, the recording period was greater than 10 year and average recording intervals of an hour were satisfactory. Monthly wind speed frequency distribution was also tabulated. The major parameter affecting the accuracy of the data was the exposure of the recording equipment to climate conditions, accordingly ca. 6% of the stations throughout the country were ignored in the analysis on grounds of inaccuracy. These data were utilised to determine annual wind speed frequency distribution, a major parameter in computing wind power density at a given site.

Anemometers were mounted on poles at a fixed height above ground, usually 5, 10 or 15 m. Under normal conditions, wind speeds were greater at higher distance above ground. This is largely because the effects of surface features and turbulence diminish as the height increases. The variability depends on distance from the ground and roughness of the terrain [6]. It is much more difficult to predict average monthly wind speeds if the reference height at which the data were recorded is less than 6 m. Data collected at heights of less than 6 m should not be used to select a windmill or predict performance [7]. In relatively flat areas with no trees or buildings in the immediate vicinity, site selection is not critical [8]. However, in mountain areas or places where obstacles may block the flow of wind, differences in surface roughness and obstacles between anemometers and pump site must be taken into account when estimating wind speeds for the site. In Sudan, unequal measuring heights at different stations, in towns like Khartoum, Wad Madani, Atbara and El Obeid were measured at 15 m, in semi-towns at 10 m, and in the remaining at 5 m [9]. The accuracy of the instruments was estimated to 5%.

The objectives of creating a wind resource database for Sudan are to:

- Analyse the wind energy potential in Sudan using available wind data for the country.
- Refine recorded data and develop an accurate estimate of global wind energy available in Sudan.
- Identify wind characteristics required for the design of wind energy conversion systems.

Data, obtained from the Meteorological Department Office, were from measurements with cup anemometers coupled to chart recorders for selected stations. Mean monthly wind speeds were tabulated for 70 meteorological stations and mean annual wind powers were derived. Based on these data, an isovent map was developed showing the distribution of wind speeds all over the country, so indicating the potential for wind energy in Sudan. Due to local conditions, there may be many high-wind sites in low-wind areas and conversely at a given site can be several times less than that calculated on the basis of mean annual wind speeds. This is due to the cubic power in the relationship between wind power and wind speed. The wind potential in Sudan is proportional to the latitude; the higher the latitude, the greater wind potential. In other words the regions below 9˚'N (tropical region) have lower wind potential than the region above 9˚'N. In the analysis of the data there were remarkable discrepancies for these reasons:

- The growth of trees around the station and new buildings.
- The quality of the maintenance and calibration of the measuring equipment.
- Replacement of measuring equipment by another type.

The mean monthly wind speeds and wind directions measured at a height of 10 m above ground for stations throughout Sudan are given in [10]. It was found that the Weibull distribution gives a good approximation for many wind regions in Sudan. The resulting shape factor k and average wind speed are presented in Table (1), indicating large wind variability in Sudan. Most cases with very stormy winds in Sudan result from three kinds of storms [10 and 11]:

- Haboob (squalls) i.e., dust storms associated with cumulus clouds (cd) which occur in the period April-September.
- Dust storms caused by steep pressure gradients for south and south-westerly winds south of the intertropical from which occur in the period May-October.
- Dust storms caused by the continental polar air reaching Sudan as cold fronts associated with strong eastern depressions. This occurs in the period February-April.

The maximum gust speed recorded for selected stations are presented in Table (1).

Station	Altitude (m)	Annual wind Speed (V) ms^{-1}	Shape factor (k)	Number of years of observation
Wadi Halfa	190	4.6	1.8	4
Port Sudan	5	5.0	1.6	10
Karima	250	4.7	1.7	10
Atbara	345	4.2	1.75	10
Shambat	380	4.8	2.1	10
Khartoum	380	4.8	1.9	10
Kassala	500	4.0	1.95	10
Wad Madani	405	4.8	1.8	10
El Fasher	733	3.4	1.15	10
El Geneina	805	3.1	1.9	10
El Obeid	570	3.4	1.9	10
Kosti	380	4.0	1.8	10
Abu Na'ama	445	3.1	2.2	10
Malakal	387	2.8	1.2	10
Wau	435	1.7	1.2	10
Juba	460	1.5	1.4	10

Table 1: Results of Weibull parameters for number of Stations.

3 DISCUSSIONS

In the last 15 years, the Energy Research Institute (ERI) has installed 15 'CWD 5000' wind pumps from the Netherlands around the Khartoum area and to the north and east. At the present time, the ERI, in cooperation with the Sudanese Agricultural Bank (SAB), is planning a further 60 wind pumps for water pumping in agricultural schemes, as financial support becomes available.

A distinction should be made between two applications:

- Water pumping for domestic water supply and cattle, for irrigation, drainage, prawn breeding and salt pans (26 machines).
- Battery charging for lighting, T.V., radio, telecommunications, etc. (3 systems are available) [4, 10 and 16].

The wind pumps are categorised as:

(1) Low lift (<6 m), high volume applications (2 pumps are available).

(2) Medium lift application (<50 m) (10 pumps).

(3) Deep-well applications (>50 m) (more than 13 pumps).

Five of the wind pumps are locally manufactured by:

(1) National Company for Manufacturing Water Equipment Limited (3 pumps).

(2) Sahara engineering Company (1 pump).

(3) University of Wadi El Neil- Atbara (1 pump).

The basic purpose of the CWD programme of the mid 1980s was for wind energy to play a significant role in meeting the rural energy needs in Sudan. This depended on a new generation of low-cost wind pump designs, which should be simple enough for local manufacture to evolve. Therefore the CWD of the Netherlands carried out consideration R & D for the Sudan wind energy project. These activities resulted in the development of acceptable wind pump designs that are suitable for application in Sudan, though the range of application may still be limited to low/medium head situations [11].

Making general conclusions about wind pumps in Sudan are limited by having only tested one type of machine (CWD 5000). Nevertheless, wind pumps are most appropriate at sites with good wind regimes (more than 4.0 m/s), and low to moderate heads (less than 50 m). Such areas are generally on the north (along the Nile basin) and on the northeast of the country (Red sea hills).

The designers' performance predictions were overestimated by 30-50% for daily average wind speed of 3-5 m/s; higher wind speed performance is impaired by rapid wear of the cup leather, which reduces the system operating efficiency. Optimally an efficiency of about 10% and a water output of about 30 litres per minute have been achieved for wind speeds of about 4.5 m/s. This efficiency was well below the designer/manufacturer's estimates. However, this might have been due to the following problems, which were frequently encountered on the field:

- Wear of the front and rear transmission bearings.
- Rapid wear of the leather cups.

The CWD 5000 has not proved to be a reliable, commercially viable design. After early problems with the furling mechanism and the pump itself were overcome, failures of the head frame assembly and the crank arm on many machines, proved that various design weaknesses urgently needed to be rectified. Nevertheless, there are technically appropriate applications in Sudan for well-designed, reliable wind pumps. The Kijito wind pumps, for example has been field-tested in Kenya and Botswana and found to be a reliable (albeit expensive) machine. The cost comparison table indicates that the necessary fuel and maintenance needed to run the diesel pump unit are the main factors that govern the overall cost, and not the capital cost of the diesel pump itself. The maintenance cost for the CWD 5000 however, was too high but this is entirely attributed to its bad design. Therefore, in the case of Sudan where the fuel is expensive, the supply is uncertain, the infrastructure is poor and areas are remote; the use of wind machines become more cost-competitive with diesel as the demand and head decrease and fuel prices and transport distances increase.

The following can be deduced from the cost comparison case:

- Initial cost of the wind pump was high compared to diesel pump.
- Costs of the maintenance of wind pumps were exceptionally high.
- Water pumping cost was more or less the same for both.

4 CONCLUSIONS

(1) Mean wind speeds of 4 ms^{-1} are available over 50% of Sudan, which suited for water lifting and intermittent power requirements, while there is one region in the eastern part of Sudan that has a wind speed of 6 ms^{-1}, which is suitable for power production.

(2) The base case financial and economic analyses show that using wind pumps for remote rural water supply is cost-effective in cases where the (demand*head) product is less than 750 m^4 for wind resources of over 4 m/s.

(3) The initial investment cost of wind pumps is high, this entirely a scale problem and local mass-production facility would substantially reduce this capital cost.

(4) The substantial wind power fluctuations necessitate the use of large storage tanks. The setting up of manufacturing facilities for module easily assembled water tank is as important as the wind pump itself.

(5) According to the investigation on demand and purchasing power of the rural people, more than 60 wind pumps will be installed before year 2007. Thus the prospects for wind pumps are increasing.

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