# Research Article Environment Conservation through the Use of Wind Energy

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Abstract Ozone depletion, global warming phenomena and other environmental problems encouraged the use of renewable energy. Special attention is given to wind energy because of its competitive ability. This work is an attempt to use wind energy to drive the large number of both manual reciprocating pumps and simple Egyptian water pumps that are distributed over a large area of Egypt. The results of this work show that this will be a good choice to use simpler and cheaper types of wind turbines like American multi-blades wind turbines to drive these pumps. This will save a considerable amount of conventional fuels that are used to drive the traditional pumps and will reduce the emission of harmful gases to great extent. It was found also that a considerable amount of water will be pumped using these wind driven pumps. The pumping amounts of water depend on wind regime in location.

**Keywords** wind energy; renewable energy; water pumping; environmental conservation; climate change

### **1** Introduction

Measurements taken from all over the world have shown that the global climate is changing and the ozone is depleted. In the last 100 years, the atmosphere has warmed up by about half a degree Celsius [1,8]. Also during this time humans have been emitting extra greenhouse gases, which are the result of burning fossil fuels (like coal, oil and gas). These gases include carbon dioxide, methane and nitrous oxide. It is thought that the man-made emissions of greenhouse gases, from the increased use of fossil fuels, are responsible for some of the warming of the global climate during the 20th century. The extra greenhouse gases in the atmosphere trap more energy and therefore enhance the greenhouse effect. This may cause more warming. If the Earth continues to warm as climate models have predicted, the temperature at the Earth's surface may be 3 °C warmer by 2100 than it is today. This rapid change in temperature would be harmful to many ecosystems, and many types of plants and animals. Climate change will affect rainfall, sea level and storm events, and humans would also be affected by these factors.

Food crops would be altered, as well as forests and water supplies. People's health will also be affected [1,7,8].

Both greenhouse warming and the thinning of the stratospheric ozone layer are a result of human activities that have changed the composition of the atmosphere in subtle but profound ways since the beginning of the industrial revolution more than 200 years ago. Climate change and the depletion of the stratospheric ozone layer have been leading environmental issues for more than a quarter of a century.

The burning of conventional sources of fuels in thermal power stations and in driving conventional water pumps is the main reason for present global climate change. Therefore, there is a great tendency in the world towards the use of renewable sources of energy [18].

The production and use of renewable energy has grown more quickly in recent years due to oil shortages of the 1970s, higher prices for oil and natural gas and the impact of conventional sources on the environment. Kris et al. discussed a methodology to accurately determine the impact of using wind-energy-conversion systems on the operation of the central power system. They found that in all cases considered, the green house gases emission reduction obtained on a national level is in the range of 350-450 kg CO<sub>2</sub> per MWh of power generated by the wind energy conversion systems [19]. Bueno et al. used a general model for the optimum design from a technical and economical point of view of medium sized wind energy/pumped hydrostorage systems in the island of El Hierro. The application of the model would allow an increase in renewable-sourced energy penetration of the island grid from the current technically permissible maximum of 30-68.40%. Such a renewable-sourced energy penetration would mean fossil fuel savings as well as a decrease in CO2 emissions of 20.9 Gg [4]. The use of renewable energy is expected to continue to grow over the next 30 years, although we will still rely on non-renewable fuels to meet most of our energy needs. In the 9th of March 2007, the European council decided a fixing goal of 20% contribution of the renewable energy sources on the total European electric energy production in 2020 [6].

In 2006, wind machines in the United States generated a total of 26.6 billion kWh per year of electricity, enough to serve more than 2.4 million households [9,14]. This is enough electricity to power a city larger than Los Angeles, but it is only a small fraction of the nation's total electricity production, about 0.4 percent. The amount of electricity generated from wind has been growing fast in recent years. In 2006, electricity generated from wind was 2.5 times more than wind generation in 2002 [1].

New technologies have decreased the cost of producing electricity from wind, and growth in wind power has been encouraged by tax breaks for renewable energy. Most of the wind power plants in the world are located in Europe and in the United States where government programs have helped support wind power development. The United States ranks second in the world in wind power capacity, behind Germany and ahead of Spain and India. Denmark ranks number six in the world in wind power capacity but generates 20 percent of its electricity from wind. During the decade following the 1973 oil crisis, more than 10,000 wind machines were installed worldwide, ranging in size from portable units to multi-megawatt turbines. In developing villages, small wind turbines recharge batteries and provide essential services [15, 17].

Although wind power supplies less than 0.1 percent of the world's electricity, it is one of the fastest growing energy sources. The most ambitious wind energy program is planned for India, which is expected to provide enough electrical power to serve 5 million customers. India is expected to be the most rapidly growing market for wind turbines and, if the planned program is successful, wind may supply more energy for India than the country's nuclear program [2].

Interest in wind energy has been driven in part by the declining cost of capturing wind energy-from more than 0.25\$ per kilowatt-hour in 1980 to 0.05\$ per kilowatt-hour for new turbines in the late 1990s. This makes wind power nearly competitive with gas- and coal-powered plants, even before considering wind's environmental advantages [2]. Encouraged by improved technology, falling costs, and government incentives like tax credits and guaranteed prices, wind power is booming across Europe. One reason for the growth in the industry is that the European Union wants to diversify its energy sources while clamping down on pollution. Almost no country supports the expansion of nuclear power and, in many areas, wind power is becoming economically viable. The latest trend in Europe is to build wind farms offshore where there is more wind and fewer complaints that they clutter the landscape.

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There are two main types of wind turbines used today based on the direction of the rotating shaft: horizontal-axis wind machines and vertical-axis wind turbines, VAWTs. The size of wind machines varies widely. Small turbines used to power a single home or business may have a capacity of less than 100 kilowatts. Some large commercial sized turbines may have a capacity of 5 megawatts. Larger turbines are often grouped together into wind farms that provide power to the electrical grid. Most wind machines being used today are the horizontal-axis type. VAWTs are more suited to commercial applications and are excellent at operating in confused wind areas. They are simpler and very effective at lower wind speeds.

In Egypt, the air pollution has reached extreme values. The main reason is the use of conventional sources of fuels in generating mechanical or electrical powers. Conventional sources of fuels are used in a wide range in Egypt in lifting water for irrigation purposes. A great number of manual reciprocating pumps are distributed over the whole area of Egypt. There are also a large number of simple old Egyptian water pumps that were driven by using animal forces, which is one of the reasons why they are not in use today. There is also other type of pumps with different sizes that are driven by diesel engines. The aim of this work is to study the possibility of using wind energy for driving these pumps as well as to study their performance. This will help in the improvement of air pollution situation in Egypt.

#### 2 Mathematical analysis

American multi-blade wind turbine which is a low-speed wind turbine is chosen to drive these pumps. This turbine is very suitable for water pumping because of its high rotation moment, in spite of its low power coefficient. It gives a maximum power coefficient of about 0.18 at optimum tip speed ratio 0.9 [13]. The rated power of this wind turbine can be expressed as

$$P_R = 0.5\rho_a A_t v_B^3 C_{pm},\tag{1}$$

where  $\rho_a$  is the air density,  $A_t$  is turbine area,  $v_R$  is the rated wind speed and  $C_{pm}$  is the maximum power coefficient. The pump uses this power to give its rated discharge according the following relation:

$$Q_R = 0.5 C_{pm} \eta_p \rho_a A_t v_R^3 / gh \rho_w, \qquad (2)$$

where  $\eta_p$  is the efficiency of the pump, g is the gravitational constant, h is the pumping head of water and  $\rho_w$  is the density of water [3, 16].

The manual reciprocating pump revolution is calculated from the relation

$$n_p = 4Q_R/\pi d_p^2 l_s,\tag{3}$$

where  $d_p$  is a manual reciprocating pump diameter, about 0.1 m, and  $l_s$  is the pump stroke, about 0.15 m [10].



Figure 1: A photo of a simple Egyptian water pump and its main parameters.

The number of revolution in the case of simple old water pump can be determined from [11]

$$n_p = 60Q_R/\pi btz d_i c_q,\tag{4}$$

where b is the pump width, t is the height of inlet port; z is the number of inlet ports,  $d_i$  is the diameter of center of inlet ports and  $c_q$  is the discharge coefficient, as shown in Figure 1.

This is the number of revolution of the system when the turbine is coupled with the pump. The number of revolution of the system when the wind turbine works without load can be estimated by

$$n_t = 60 v_R \lambda_{\rm op} / \pi d_t, \tag{5}$$

where  $\lambda_{op}$  is the optimum tip speed ratio.

The discharge from wind driven pump at any wind speed v can be expressed as

$$Q_v = Q_R \left(\frac{n_{pv}}{n_p}\right),\tag{6}$$

where  $n_{pv}$  is the number of revolution of pump at any wind speed [5, 16].

The discharge from wind driven pump at different values of wind speed, starting from start wind speed  $v_c$  which is 0.4  $v_R$  to furling wind speed  $v_f$  which is 2  $v_R$ , can be calculated for different locations in Egypt related to wind regime in each location. Table 1 shows the average wind speed  $v_{av}$ , Weibull shape parameter k, Weibull scale parameter c as well as rated wind speed  $v_R$  for each one of the chosen locations.

The average wind speed and Weibull parameters for each location are obtained according to [12], while the rated wind speed is selected for each location to achieve best economy

| Location     | $V_{\rm av}$ , m/s | k    | <i>c</i> , m/s | $v_R$ , m/s |
|--------------|--------------------|------|----------------|-------------|
| Mersa Matruh | 5.4                | 1.85 | 5.961          | 11          |
| Hurghada     | 6.69               | 1.89 | 7.412          | 13.5        |
| Ras Benas    | 6.08               | 1.49 | 5.99           | 12.99       |
| Aswan        | 4.48               | 2.17 | 5.03           | 8.6         |
| El-mansoura  | 2.99               | 1.56 | 3.29           | 7.11        |

**Table 1:** Average wind speed  $v_{av}$ , Weibull shape parameter k, Weibull scale parameter c as well as rated wind speed  $v_R$  for each one of the chosen locations.

according to [11]. Monthly wind speed frequency distribution has been obtained for these locations from the Egyptian meteorological authority. This data was measured for a long period of more than 20 years at 10 m level above ground surface. The wind speed was divided into 8 intervals and the wind speed frequency was measured for each interval.

To estimate the daily and yearly pumping amount of water for each location, the average discharge in each location must be calculated first as

$$Q_{\rm av} = \frac{60Q_R\lambda_{\rm op}}{\pi d_t n_p} \int_{v_c}^{v_R} vf(v)dv + Q_R \int_{v_R}^{v_f} f(v)dv, \qquad (7)$$

where f(v) is the Weibull distribution function

$$f(v) = \frac{k}{c} \left(\frac{v}{c}\right)^{k-1} \exp\left(-\left(\frac{v}{c}\right)^k\right).$$
(8)

The pumping amount of water  $Q_{\rm tot}$  can then be estimated as

$$Q_{\rm tot} = Q_{\rm av} \text{ time.} \tag{9}$$

The diameter of wind turbine used to drive the manual reciprocating pump is taken as 3 m, while the diameter for the turbine used to drive the simple Egyptian water pump is taken as 5 m for operation suitability consideration.



Figure 2: Relation between the flow rate and the number of revolution of manual reciprocating pump with wind speed.



**Figure 3:** Relation between the flow rate and the number of revolution of simple Egyptian water pump with wind speed.



**Figure 4:** Predicted daily and yearly pumping amount of water by a manual reciprocating pump and by a simple Egyptian water pump.

### **3** Results and discussion

Figure 2 shows the relation between the flow rate and the number of revolution of a manual reciprocating pump with wind speed for a location with a relative high wind speed, Hurghada. Figure 3 represents the same relation in the case of a simple Egyptian water pump. It is shown that the flow rate and the number of revolution of pump increase with the increase in wind speed in location. At the same value of wind speed, the flow rate of water from simple Egyptian water pump is more greater than the flow rate from manual



Figure 5: Relation between the flow rate and the number of revolution of manual reciprocating pump with wind speed.



Figure 6: Relation between the flow rate and the number of revolution of simple Egyptian water pump with wind speed.

reciprocating pump in spite of the smaller value of number of revolution. The reason for that is the difference in both geometry and size of the two pumps. The size of a simple Egyptian water pump is larger.

Figure 4 illustrates the predicted daily and yearly pumping amount of water by a manual reciprocating pump and a simple Egyptian water pump.

Figures 5, 6 and 7 are the corresponding curves for Elmansoura which has a low average wind speed. The curves show the same trend as the above corresponding curves for Hurghada. The above curves illustrate also that sites with a good wind regime like Hurghada will have higher values of flow rate, number of revolution as well as pumping amount of water than sites with low wind like El-mansoura.

The flow rate from a manual reciprocating pump and from a simple Egyptian water pump in five locations in Egypt with different wind regimes is presented in Figures 8 and 9, respectively. The sites with a good wind regime like Hurghada, Ras Benas and Mersa Matruh have higher flow rates from both manual reciprocating pump as well as from simple Egyptian water pump. While sites with a poor wind regime like El-mansoura and Aswan have lower flow rates.



**Figure 7:** Predicted daily and yearly pumping amount of water by a manual reciprocating pump and a simple Egyptian water pump.



**Figure 8:** Relation between the flow rate from a manual reciprocating pump and the wind speed in five locations in Egypt.



**Figure 9:** Relation between the flow rate from a simple Egyptian water pump and the wind speed in five locations in Egypt.

The yearly pumping amounts of water from manual reciprocating pump and from simple Egyptian water pump for different locations in Egypt are shown in Figures 10 and 11, respectively. It is seen that the pumping amount of water by wind driven manual reciprocating pump and by simple Egyptian water pump is very reasonable. Therefore, the use of wind driven manual reciprocating pumps as well



**Figure 10:** Predicted yearly pumping amount of water by manual reciprocating pump in five locations in Egypt.



**Figure 11:** Predicted yearly pumping amount of water by a simple Egyptian water pump in five locations in Egypt.

as simple Egyptian water pumps will be very attractive in these studied locations.

Using wind energy to drive these types of pumps will not only be attractive but it saves also a great part of conventional sources of energy which are used till now to drive these pumps. Two main benefits will be achieved from this process: saving money paid to obtain the conventional sources of energy and reducing of harmful gases emitted from burning of these sources. An improvement of environment in Egypt is consequently achieved.

#### **4** Conclusions

This work is an attempt to improve the environment in Egypt through the use of wind energy to drive the old traditional water pumps. This will help in reducing the number of pumps that use conventional fuels which are the main reason of environmental pollution.

The results of this work show that the use of wind energy to drive the great number of both manual reciprocating pumps and simple Egyptian water pumps that are distributed over a large area of Egypt will be a very good choice. This will save a considerable amount of conventional fuels used to drive the traditional pumps and will reduce the emission of harmful gases to a great extent. Simpler in construction and cheaper types of wind turbines, like American multi-blade wind turbines, can be used to drive these pumps. This turbine when it is used to drive a manual reciprocating pump and a simple Egyptian water pump gives a reasonable pumping amount of water. This pumping amount is related to the wind regime in position. In locations having a good wind regime, like Hurghada, the daily and yearly pumping amounts of water by manual reciprocating pump are about 2100 and 785,000 m<sup>3</sup>, respectively. The daily and yearly pumping amounts of water by simple Egyptian water pump in this location were found to be about 4300 and  $1.6 \times 10^6$  m<sup>3</sup>, respectively.

## Nomenclature

- $A_t$  rotation area of wind turbine, m<sup>2</sup>
- *b* simple pump width, m
- C Weibull scale parameter, m/s
- $C_{pm}$  the maximum power coefficient, —
- $c_q$  discharge coefficient, —
- $d_i$  diameter of center of simple pump inlet ports, m
- $d_p$  manual reciprocating pump diameter, m
- f(v) Weibull distribution function
- g gravitational constant
- *h* pumping head of water, m
- $l_s$  pump stroke, m
- $n_p$  pump revolution, rpm
- $n_{pv}$  number of revolution of pump at any wind speed, rpm
- $n_t$  number of revolution of the system without load, rpm
- $P_R$  rated power of wind turbine, W
- $Q_{\rm av}$  average discharge in each location, m<sup>3</sup>/s
- $Q_R$  rated discharge from wind driven pump, m<sup>3</sup>/s
- $Q_{tot}$  total pumping amount of water, m<sup>3</sup>
- $Q_v$  discharge from wind driven pump at any wind speed v, m<sup>3</sup>/s
- t height of simple pump inlet port, m
- v wind speed, m/s
- $v_c$  start wind speed, m/s
- $v_f$  stop wind speed, m/s
- $v_R$  rated wind speed, m/s
- z number of inlet ports, —
- $\rho_a$  air density, kg/m<sup>3</sup>
- $\rho_w$  density of water, kg/m<sup>3</sup>
- $\eta_p$  efficiency of the pump, —
- $\lambda_{\rm op}$  optimum tip speed ratio, —

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