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FEASIBILITY OF WIND ENERGY UTILIZATION IN QATAR*

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ABSTRACT

This work presents an assessment of the potential and economical feasibility of adopting wind energy as a renewable source of energy in Qatar. An analysis is presented for the long term measured wind speed (1976-1989) at Doha International Airport. The average annual wind speed was found to be about 4.4 m/s, which indicates the suitability of utilizing only small wind turbine generators, efficiently. Such small generators can be implemented for water pumping and to produce sufficient electricity to meet vital, limited needs of remote locations, such as isolated farms, which do not have access to the national electricity grid.

An economical assessment is presented which takes into consideration the interest recovery factor, the life time of the wind energy conversion system (WECS), the investment rate and operation and maintenance costs. The results indicate that the cost of electricity generation from the wind in Qatar compares favorably to that from fossil fuel resources.

1. INTRODUCTION

Wind power is one of the world's fastest growing energy sources. In 1993, the world generated wind energy was approximately 2,500 MW and rose to around 11,000 MW by the end of 1999. Fig. 1 illustrates the current and projected installations of wind power until 2005. This rapid growth is the result of improved efficiency and reduced cost of wind turbines to a level that makes power generation from the wind competitive to that from conventional sources. Furthermore, there is an added advantage that wind power is a non polluting source of energy.

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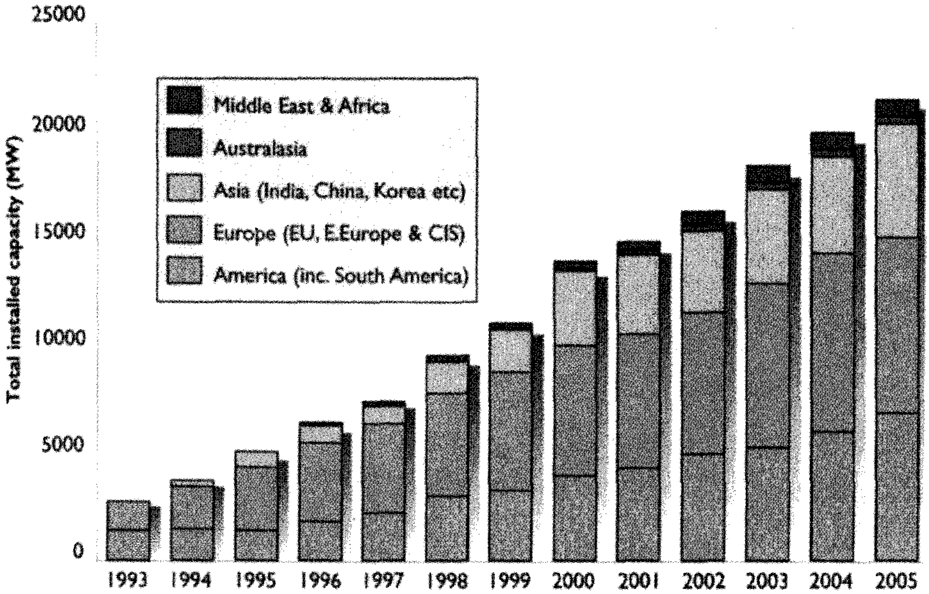

Fig. 1. Growth in wind power installations worldwide [1, 2].

Energy consumption in Qatar has grown rapidly over the years, Fig. 2. This growth can be attributed to rising population, living standards and industrialization. Almost 80% of the generated electricity is used for air conditioning. The generated electricity uses natural gas and petroleum. Fossil fuels are, however, depleted resources and should be conserved. This can be achieved by several means. One approach is by adopting energy conservation measures such as proper insulation in buildings and promoting public awareness of energy conservation benefits. Another approach is to encourage research in renewable energy resources that can be applied to the region.

Several researchers investigated the feasibility of wind energy utilization in the Arabian Gulf region [4, 5].

In this paper an assessment and economical evaluation of wind as a potential source of energy is undertaken. Particular attention is focused on wind energy utilization for the production of electricity.

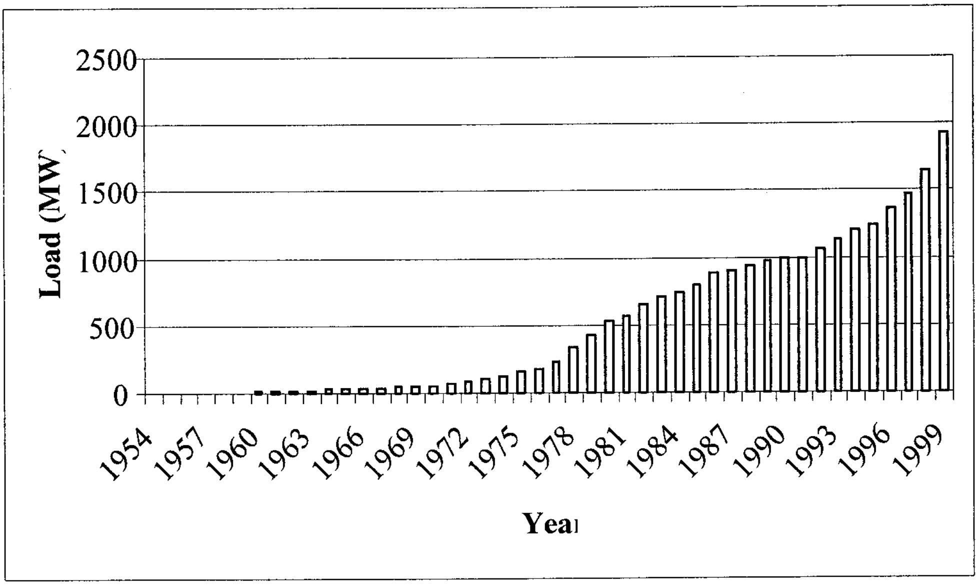

Fig. 2. Energy consumption in Qatar [3].

2. DATA COLLECTION

Wind speed and direction are recorded on hourly basis at the meteorology Department near Doha International Airport. A typical set of long term data covering a period of 14 years from 1976-1989, is used in the following analysis. The set of data for the period from 1990-2000 is currently being acquired and will be analyzed and incorporated with the (76-89) set of data in a follow up work. The wind speed was measured at a height of 10 m above the ground level. Fig. 3 illustrates the long term monthly variation in wind speed. The highest average monthly wind speed was during June (5.2 m/s) and the lowest was during September (3.5 m/s).

The annual mean frequency of various wind speed ranges for the period (1976-1989), is illustrated in Fig. 4. Fig. 4 indicates that wind speeds in the range of 3 to 4.5 m/s have the highest frequency occurrence during the year (25%) followed by 1.5 to 3 m/s (20.1%) , followed by 4.5 to 6 m/s (19.6%), followed by 6 to 7.5 m/s (13.9%). Since the minimum required wind speed for a wind park is about 3 m/s, a typical turbine will operate about 76% of the time throughout the year.

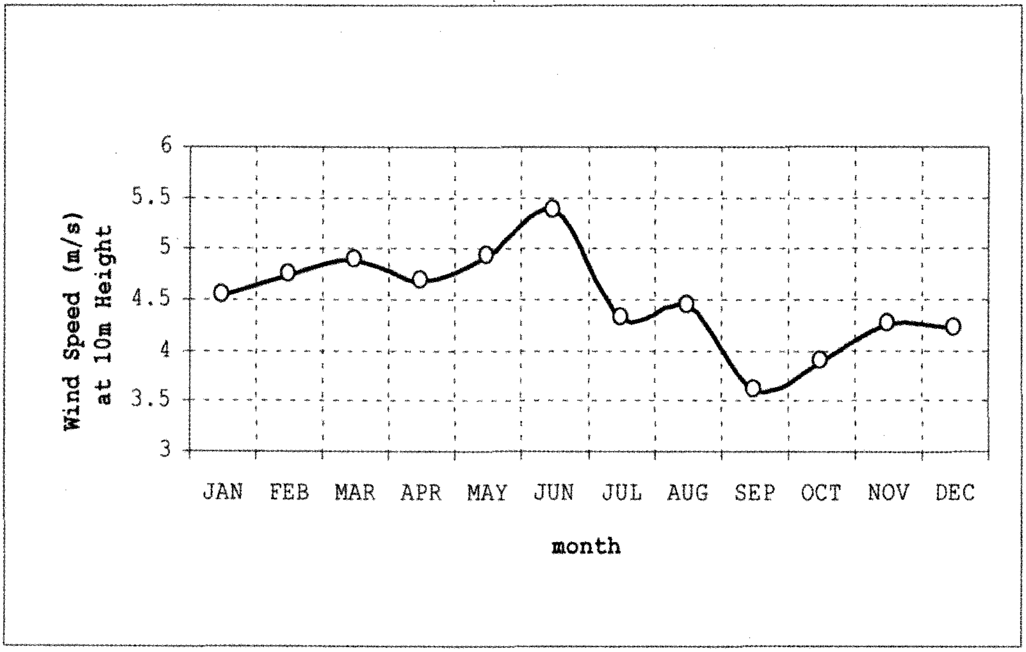

Fig. 3 Mean monthly variation of wind speed in Doha (1976-1989).

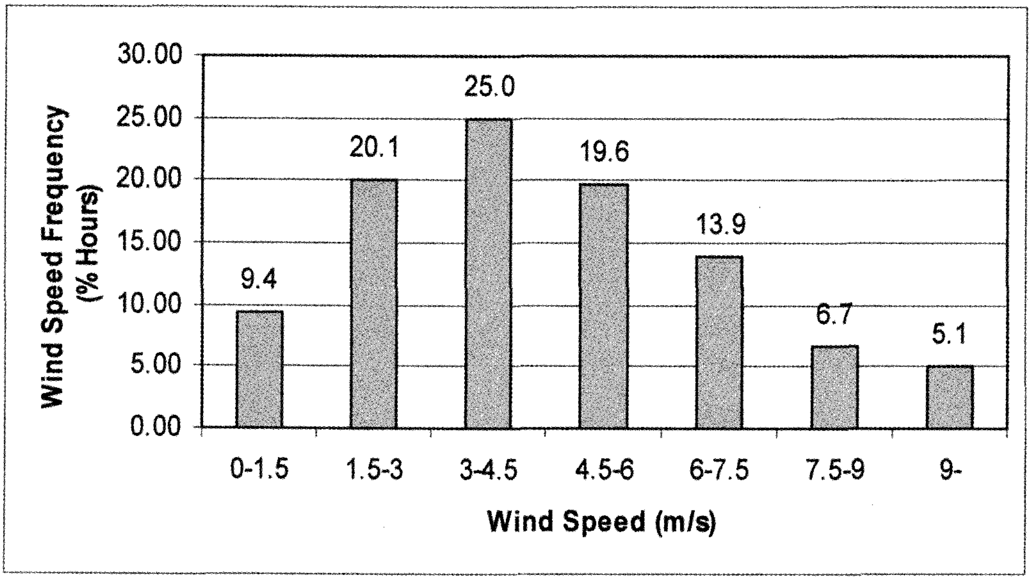

Fig. 4 Mean hourly wind speed frequency for Doha (1976-1989).

3. WIND CHARACTERISTICS

Wind fluctuates constantly both in speed and direction. On the other hand, wind speed is also dependent on the height above the ground level. Several researchers have investigated the effect of height on wind speed. One proposed correlation is [6, 7]:

$$V = V_0 \,.\, (H/H_0)^{\alpha} \tag{1}$$

Where

V_0 is the wind speed at height H_0 = 10 m above the ground level
V is the wind speed at altitude H (m)
α is a power index constant which depends on site type (0.1 - 0.4) [8].
In our case α is assumed to equal 0.24.

The power contained in the wind is directly proportional to the cubic wind speed. Consequently, accurate wind speed data is essential for accurate evaluation of available wind power. The recorded data at meteorological centers are usually in the form of tables of wind speed intervals and time duration on an hourly, daily, monthly, and/or yearly basis. The average wind speed, V, can be approximated using the recorded data as follows [9]:

$$V = \sum (V_i \,.\, T_i^*) \tag{2}$$

Where

V_i is the mean wind speed for the *i*th interval and
T_i^* is the number of hours corresponding to the *i*th interval divided by the total number of hours = T_i/T_{total}.

Hence, the total available power in a cross-sectional area perpendicular to the wind stream moving at speed V can be expressed per unit area as follows:

$$P_a = 0.5\, \rho \sum (Vi^3 \,.\, T_i^*) \quad (W.m^{-2}) \tag{3}$$

$$\rho = 3.485\, P / T \tag{4}$$

Where

ρ is the air density,
P is the air pressure (kPa) and

T is the air temperature (^oK).

The total extractable power P_e, is the power which can be extracted from the wind. It depends on the available wind power and the operating characteristics of the wind turbine:

$$P_e = 0.5\ \rho\ .\ C_p \sum (V_i^3\ .\ T_i^*) \qquad (W.m^{-2}) \qquad (5)$$

Where C_p is a power coefficient ($C_p = 0.59$ for an ideal rotor).

Taking $P = 94.7$ kPa, and $T = 302$ ^oK for Qatar, the density $\rho = 1.093$ kg. m^{-3} and the extractable power becomes:

$$P_e = 0.322 \sum (V_i^3\ .\ T_i^*) \qquad (W.m^{-2}) \qquad (6)$$

The capacity factor, F_c, is a function of the wind characteristics at a given site and the turbine power curve, and is governed by the wind turbine cut in-cut out speeds and efficiency. It can be defined as follows:

$$F_c = E_g / E_r \qquad (7)$$

Where

E_g is the actual energy generated by the turbine per year.
E_r is the turbine rated energy capacity if it operates all the time.

A wind turbine will not generate power when the wind velocity is below the cut-in speed, V_{ci}, or higher than the cut-out speed, V_{co}. Furthermore, the wind turbine output is usually constant at its rated output in the range of wind speeds between its rated speed, V_r, and the cut-out speed. The turbine generated power corresponding to a typical mean interval wind speed, V_i, in the range between the cut-in speed and the rated speed, can be approximated by [6]:

$$P(V_i) = P_r (V_i^2 - V_{ci}^2) / (V_r^2 - V_{ci}^2) \qquad (\text{for } V_{ci} \leq V_i \leq V_r) \qquad (8)$$

Where P_r is the rated power.

The actual amount of energy generated, is the summation of power over the total time period:

$$E_g = (\Sigma_i\ P_r (V_i^2 - V_{ci}^2) / (V_r^2 - V_{ci}^2).\ T_{i.}) \qquad (\text{for } V_{ci} \leq V_i \leq V_r)$$

$$+ (\Sigma_i P_r . T_i) \qquad (\text{for } V_i > V_r) \qquad (9)$$

The rated energy can be calculated as:

$$E_r = P_r \, . \, T_{total} \qquad (10)$$

Where T_{total} is the total time period.

The specific output, T_s, is defined as the ratio of the generated energy to the rated power [9]:

$$T_s = E_g / P_r \qquad (\text{kWH/kW}) \qquad (11)$$

Consequently,

$$T_s = (\Sigma_i (V_i^2 - V_{ci}^2) / (V_r^2 - V_{ci}^2). T_i) \qquad (\text{for } V_{ci} \leq V_i \leq V_r)$$
$$+ (\Sigma_i T_i) \qquad (\text{for } V_i > V_r) \qquad (12)$$

4. ECONOMICAL ANALYSIS

The cost of generating electricity, irrespective of the source, depends on several factors such as the capital cost; fueling, operation and maintenance costs; financing cost; the plant productivity; and the life time of the plant. Renewable energy generation sources, such as wind, have a distinct characteristic of eliminating fuel cost. Consequently, once the plant is built, the energy costs are largely fixed and only slightly affected by inflation. However, the productivity is highly site specific, as it depends on wind speed; hence the cost of energy cannot be universally defined.

Generation of electricity by burning fossil fuels incurs elements of cost which conventionally are not directly related to these processes. Such costs are termed "External" costs. They originate, for example, in areas such as additionally provided infrastructure, research and development, and environmental pollution control. In contrast, renewable energy technologies such as wind turbine generators incur marginal external costs.

Generation cost can be determined from the following relation:

$$G = C\,R / E + f + m \qquad (13)$$

Where

G is the total cost per unit energy output (ECU/kWh)
C is the initial capital cost (ECU/kW)
R is the capital recovery factor
E is the annual energy yield (kWh/kW/yr) = $F_c \cdot T_{total} = T_s$
f is the fuel cost per unit energy output (ECU/kWh)
m is the operation and maintenance cost per unit energy output (ECU/kWh)

The capital recovery factor, R, varies according to the period over which the capital is to be recovered, n years, and the annual interest rate, r, thus [10]:

$$R = r / [1-(1+r)^{-n}] \quad (14)$$

The cost of electricity generation from a particular source is generally dependent upon a combination of all these variables.

5. ECONOMICAL EVALUATION

An economical analysis is presented to compare the generation cost of electricity (ECU/kWh) from both wind and gas turbine systems. To calculate the generation cost of the Gas Turbine, we assumed 20 years for the unit lifetime, 8% interest rate, and that the unit will operate at its rated power for 16 hours a day, 9 months a year (4,320 hrs). On the other hand, the cost of wind power generation is divided into the following:

1. Capital Cost: Building power plant and possibly connecting to the grid.
2. Running Cost: Operating, fueling, and maintaining the plant.
3. Financing: Cost of repaying investors and Banks.

In the present analysis, we assume [11]:

- Wind turbine cost: = 600 – 900 ECU/kW
- Project prep. & installation: = 200 – 250 ECU/kW
- Total capital cost = 800 ECU/kW
- On-going running cost (Land rent, maintenance, insurance premium):
  = 0.01 ECU/kWh

Table 1 presents an estimation of the generation cost per unit energy output for both a gas turbine and a wind turbine. In the analysis, we assume for the wind turbine that $V_{ci} = 3$ m/s and $V_r = 7$ m/s, which is a reasonable assumption for small wind turbines.

The estimation shows that generation cost from wind energy compares favorably with the generation cost for a conventional gas turbine. The continuously dimensioning capital cost of wind energy systems and the currently falling interest rates promise to make wind energy systems even more economically viable energy resource. Figure 5 presents generation costs of a wind turbine for various capital costs and various interest rates, together with the generation costs for the gas turbine presented in Table 1.

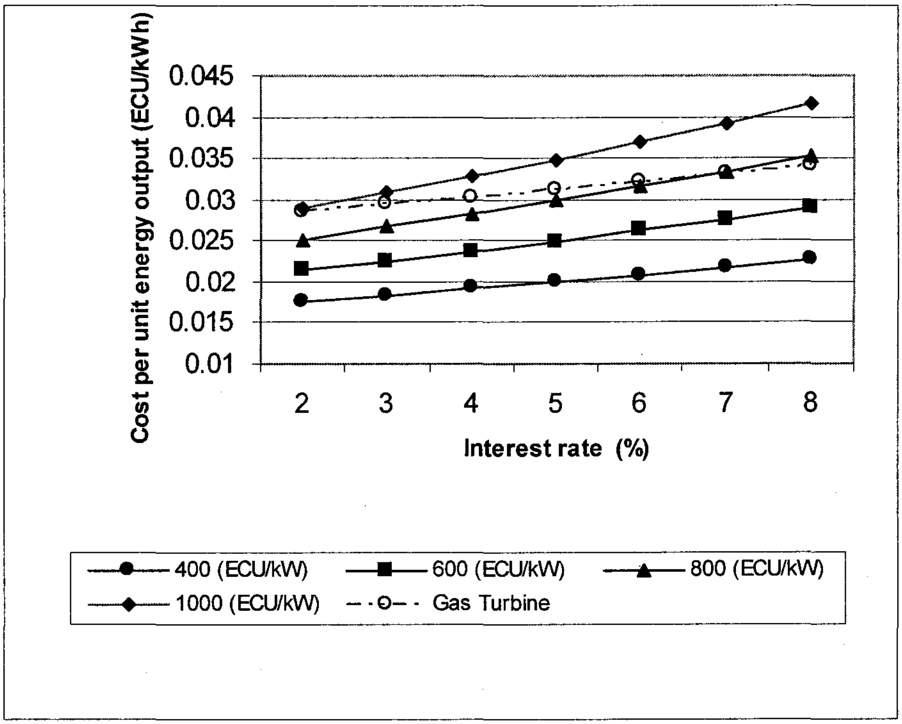

Fig. 5. Effect of capital cost and interest rate on wind energy generation cost.

Table 1. Comparison of energy generation costs using wind and gas turbines

	Factors Affecting Cost				Generation Costs per unit energy output (ECU/kWh)			
Energy Source	Capital & Inst (ECU/kW)	Energy produced (kWh/kW/yr)	Plant life (years)	Interest Rate (%)	Capital (CR/E)	Fuel (*f*)	O& M* (*m*)	Total Cost
Wind	800	3229	20	8	0.0252	0.0	0.01	0.0352
Gas Turbine	600	4320	20	8	0.0141	0.015	0.005	0.0341

* Operation and Maintenance

6. CONCLUSIONS

In the early 1980's, when early large scale wind turbine farms were installed, the higher capital cost of wind energy systems put such systems at a disadvantage compared with other conventional energy technologies. However, the continuously falling capital cost of wind energy systems coupled with the current trend of falling interest rates, make utilizing the environmentally friendly wind energy technology becoming more and more attractive. The current analysis indicates that presently wind energy generation can be economically competitive with other conventional energy sources.

In the State of Qatar, where the average wind speed is about 4.4 m/s, utilization of small wind energy systems can prove to be both efficient and competitive. Small generators can be implemented for water pumping and to produce sufficient electricity to meet vital, limited needs of remote locations, such as isolated rural homes and farms, which do not have access to the national electricity grid.

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