A Method for Determining the Suitability of Commercial Wind Machines for a Given Wind Regime

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ABSTRACT

A simple method which can be used to evaluate the suitability of the performance characteristics of commercial wind machines for a particular wind regime at a proposed installation site is presented.

To illustrate an application of the method, two models of a commercial wind machine, designed to be operated in Northern Europe, were simulated to operate at a wind site, called "Ubon," in Thailand. The results showed that their performances were not satisfactory for the wind regime there. In fact, the wind machines were hardly operational. This is attributed to the fact that both wind machines were designed to be operated at a high wind speed, whereas at Ubon wind speeds are generally low.

Although a large wind machine is designed to deliver high rated power output, it also needs a high cut-in wind speed. Hence, one has to properly match the rated power output of the wind machine with the prevailing wind speeds at a proposed installation site in order to optimally harness the available wind energy.

INTRODUCTION

Many small commercial wind machines have been imported to developing countries to provide an alternative energy source. In general, the energy generated is used to improve the standard of living of people in rural areas.

However, the implementation of these imported commercial wind machines requires careful planning since the wind machines are generally designed for a specific wind regime only. If they are operated under different wind conditions from the specific wind regime for which the machines were originally designed, their performances are much lower than one would expect.

This paper presents a simple method which can be used to evaluate the performances of wind machines to ascertain their suitability for a particular wind regime at any location.

WIND ENERGY RESOURCE EVALUATION

The fundamental problem in the utilization of wind power is to determine how much power is available at a site, its frequency, and at what reliability the wind speeds are maintained at a particular site.

Generally, an assessment of the availability of wind energy resources over a region is given by two statistical parameters of the Weibull distribution, the shape parameter k (dimensionless) and the scale parameter c (m/s). A wind regime of the wind speed frequency distribution function $f(v)$ is given by

$$f(v) \quad = \quad (k/c)\,(v/c)^{k-1}\,\exp\left(-\,(v/c)^{k}\right) \tag{1}$$

and its cumulative distribution function $F(v)$ is given by

$$F(v) \quad = \quad 1 - \exp\left(-\,(v/c)^{k}\right) \tag{2}$$

The two Weibull parameters of k and c can be obtained by analyzing wind speeds at the site or by using the data recorded at a nearby meteorological station. A method to analyze wind speed records to obtain k and c was given in reference [1].

The available wind energy is converted to useful mechanical or electrical energy by the extraction of a wind machine rotor. In order to gauge the performance of a wind machine, it needs to be compared with the performance of an ideal wind machine.

A theoretical calculation of energy availability from the ideal wind machine can be determined over a time period such as one day, one month or one year. For convenience, in this study, the calculation will be made for a one day time period.

Energy output available from the ideal wind machine is given by the following equation:

$$E_I \quad = \quad (1-F_c)\,T\int_0^{\infty} P_I(v) f(v)\,dv \tag{3}$$

where, E_I = the estimated maximum energy output available from the ideal wind machine in a one day time period (J/day),
F_c = the observed frequency fraction of calm period during a day,
T = the duration of the wind machine's operation in a one day time period (s),
$P_I(v)$ = the power output generated by the ideal wind machine (W),
$f(v)$ = the wind speed frequency distribution function,
v = wind speed (m/s).

The integral $\int_0^{\infty} P_I(v) f(v)\,dv$ is the average power generated by the ideal wind machine. F_c, the fraction of calm period during a day is included in the equation because the wind speed frequency distribution function, $f(v)$, represents only the condition when the wind is blowing ($v > 0$).

The power output, $P_I(v)$, obtained from the ideal wind machine is given by

$$P_I(v) \quad = \quad \frac{1}{2}\,C_B\,\rho\,v^3 A \tag{4}$$

where, C_B = Betz limit = 0.59
ρ = density of air at the site (kg/m^2)
= 1.16 kg/m^2 in Thailand.
A = swept area of the ideal wind machine's rotor in m^2 and is assumed to be equal to that of the commercial wind machine.

Putting $dF(v) = f(v)\,dv$, equation (3) can be numerically solved to obtain an approximate solution with the help of the equation (4) as

$$E_I \cong (1-F_c)T \sum_{i=0}^{i=\infty} [\,0.5\,(P_I(v_i) + P_I(v_{i+1}))\cdot(F(v_{i+1}) - F(v_i))\,] \quad (5)$$

Similarly, energy output available from a commercial wind machine is given by

$$E_a = (1-F_c)T \int_{v_o}^{v_n} P_a(v)f(v)\,dv \quad (6)$$

where E_a = the estimated total energy output available from the commercial wind machine in a one day time period (J/day).

$P_a(v)$ = the power output generated by the commercial wind machine (W).

v_o = cut-in speed of the commercial wind machine. At wind speed below v_o, the wind machine generates zero output.

v_n = cut-out speed of the commercial wind machine. At wind speed above v_n, the wind machine is shut down and generates zero output.

Equation (6) can be approximated as

$$E_a \cong (1-F_c)T \sum_{i=0}^{i=n-1} [\,0.5\,(P_a(v_i) + P_a(v_{i+1}))\cdot(F(v_{i+1}) - F(v_i))\,] \quad (7)$$

$P_a(v)$ of the wind machine can be determined from its performance curve supplied by the manufacturer. The power output, $P_a(v)$, is generally given as a curve versus wind speeds; its cut-in and cut-out speeds are also given. Some wind machines might have no cut-out speed.

By comparing equation (5) with equation (7), one can evaluate how fit the wind machine is to the wind regime at the site.

AN EVALUATION OF WIND MACHINES

To illustrate an application of equation (5) and (7), two models of commercial wind machines [2] designed for use in Northern Europe were evaluated to ascertain their suitability for installation at a site in Thailand.

The performance curves of the two models, Model A and Model B, are given in Fig. 1. The rated electric power generation of Model A is 22 kW at a wind speed of 14 m/s, and the rated electric power generation of Model B is 108 kW at a wind speed of 17 m/s. Model A has an swept area of 78 m² (9.8 m dia.), whereas Model B's swept area is 284 m² (19 m dia.). Both possess cut-in speeds at 4 m/s; there are no cut-out speeds.

Wind regimes at Ubon in Thailand were chosen to see whether they are suitable for the deployment of these two wind machines or not. Ubon is located in the central land mass of the north-eastern plateau of Thailand. An assessment of wind resources at the site was previously conducted by Exell [1]. Weibull parameters of the wind speed frequency distribution at the site and its observed calm fraction were analyzed for four three month periods. The results were published in Reference [1] and are reproduced here in Table 1.

Table 1. Weibull parameters of wind speed frequency distribution, time fraction of calm periods and mean wind speeds at Ubon, as reported by Exell [1].

Period	k	c (m/s)	Fraction of Calm Periods (%)	Calculated Mean Wind Speed (m/s)
Feb-Apr	1.2	2.82	29.4	1.87
May-Jul	1.2	2.47	23.5	1.77
Aug-Oct	1.2	2.67	33.8	1.66
Nov-Jan	1.2	4.20	25.5	2.94

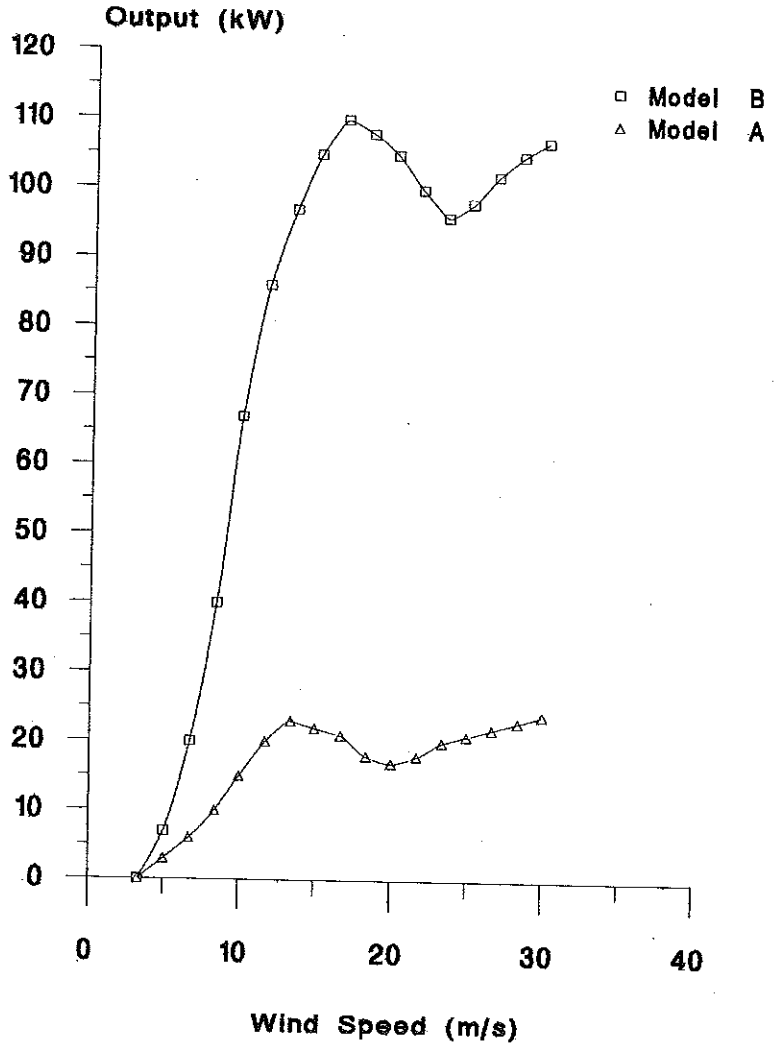

Fig. 1. The performance characteristics of wind machines Model A and B.

By using parameters c, k and F_c of the site and with the help of equation (5), one can obtain the estimated maximum energy output available from the ideal wind machine. By using the power distribution curves of each wind machine (presented in Fig. 1) corresponding to the wind speed distribution of the wind regimes at the site, and with the help of equation (7), the estimated energy output available from the wind machines can be obtained.

RESULTS AND DISCUSSION

The results are given in Table 2. For ease of comparison, the energy outputs of both wind machines are normalized to a per unit square metre of their swept areas. The ratio of the estimated energy output of each model to the output of the corresponding ideal wind machine with equal swept area was also calculated to obtain their comparative efficiencies.

Figures 2 to 5 illustrate the distribution of wind duration, and specific (normalized) wind energy generated by each wind machine during a day as a function of wind speeds.

Although the average estimated energy outputs delivered by wind machines Model A and B are about 85.4 MJ/day and 354.5 MJ/day, respectively, the normalized energy outputs show no significant difference. The energy outputs delivered by both models are only about 50% of the ideal wind machines. This is because both wind machines were designed to deliver energy at high rated power outputs, which are only attainable by operating in a high wind speed environment. Unfortunately, wind speeds at Ubon are generally low with an average wind speed of about 2-3 m/s, whereas the cut-in speeds of both wind machines are at 4 m/s. As a result, the wind machines are operational only for a small fraction of the total duration of available wind energy input.

Although large wind machines generally generate more power at higher wind speeds, their potential high power outputs are not realizable at a site which possesses a low mean wind speed. As a result, there is a compromise between a high rated power output and its availability. As is evident in Figs. 2 to 5, the peak power outputs occur at a wind speed of about 7 to 9 m/s. At this wind speed, Model A and B generate about 10 kW and 40 kW of power, respectively, but this is only attainable for a very small fraction of the day.

Table 2. The estimated energy output per square meter per day delivered by the wind machines model A and B at Ubon, as compared to the ideal wind machine.

Period	Model A ($MJ\ m^{-2}/d$)	Model B ($MJ\ m^{-2}/d$)	Ideal Wind Machine ($MJ\ m^{-2}/d$)	Eff. of A (%)	Eff. of B (%)
Feb-Apr	0.85	0.92	2.02	42	46
May-Jul	0.60	0.64	1.53	39	42
Aug-Oct	0.68	0.72	1.63	42	44
Nov-Jan	2.41	2.42	5.42	44	45

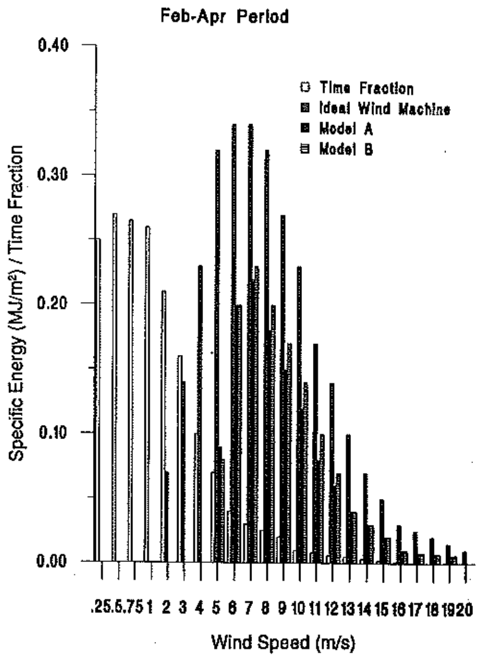

Fig. 2. Distribution of wind duration, specific energy outputs of wind machines for a one day time period of operation during the Feb-Apr period.

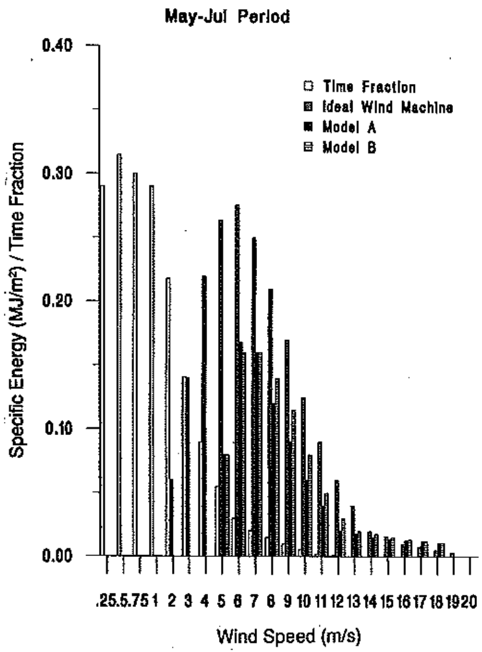

Fig. 3. Distribution of wind duration, specific energy outputs of wind machines for a one day time period of operation during the May-Jul period.

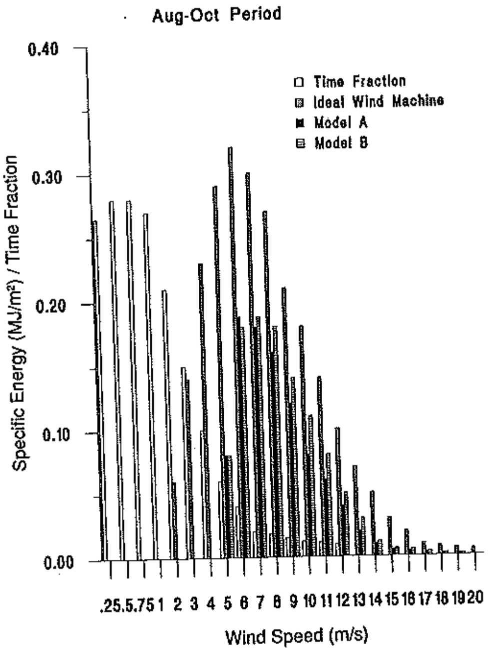

Fig. 4. Distribution of wind duration, specific energy outputs of wind machines for a one day time period of operation during the Aug-Oct period.

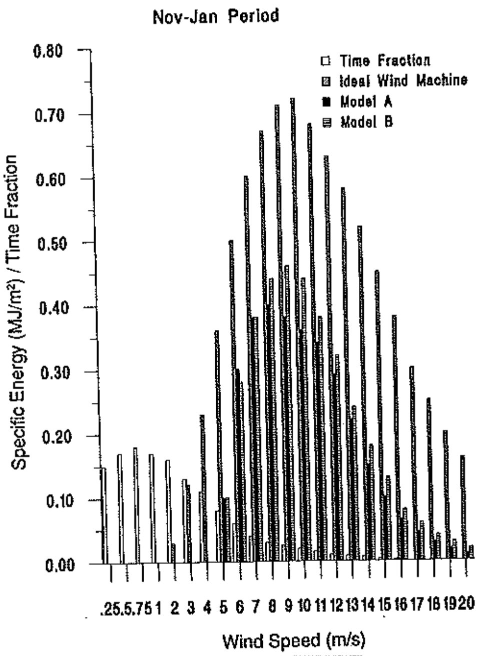

Fig. 5. Distribution of wind duration, specific energy outputs of wind machines for a one day time period of operation during the Nov-Jan period.

Wind machines can deliver more energy if they are matched to a given wind regime. To present this fact, we assumed that a wind machine, Model C, possesses an efficiency of 23% at its rated wind speed, which is similar to that of Model B. However, its cut-in speed and rated wind speed are assumed to be 3 m/s lower than Model B's, and its cut-out speed is assumed to be at 20 m/s. In other words, the cut-in speed and the rated wind speed of Model C are at 1 m/s and 14 m/s, respectively. Since the rated wind speed of Model C is lower than that of Model B, this means that the maximum power output of Model C is also lower than that of Model B.

Generally, the performance curves of electric power generation wind machines can be simplified and assumed to be linear [3]. For ease of analysis, the performance curve of the wind machine Model C for this analysis is thus assumed to be linear, as shown in Fig. 6. By knowing the efficiency of the power output of Model C at its rated wind speed and with the help of equation (4), its power output per unit area at the rated wind speed can be calculated and was found to be 216 W/m^2(the rated power outputs per unit area of Model A and Model B are 282 W/m^2 and 380 W/m^2, respectively).

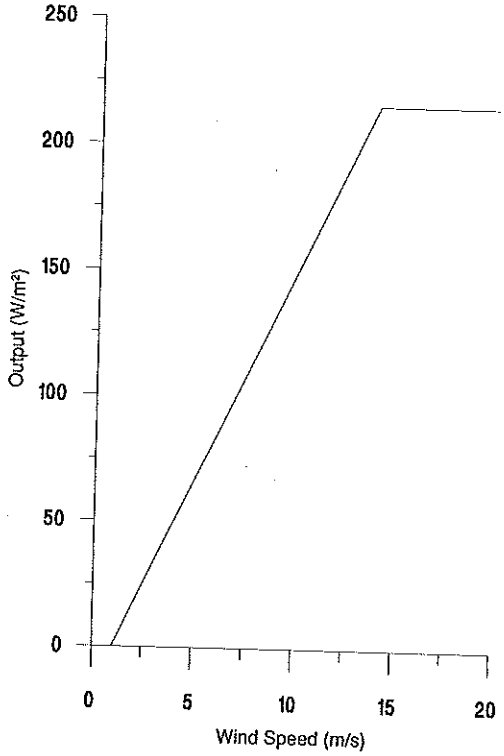

Fig. 6. The performance characteristics of wind machine Model C (normalized to power per unit area).

By using equation (7) and the method mentioned above, the estimated energy output available from the wind machine Model C can be obtained as given in Table 3. As can be seen, the efficiencies of the estimated energy output available from the wind machine Model C are significantly better than those of the wind machine Model B, ranging from 10% to 19% during the Feb-Apr to Aug-Oct period. However, their efficiencies show no difference during the Nov-Jan period.

Table 3. The estimated energy output per square meter per day delivered by the wind machine model C at Ubon and increases in its energy output efficiencies, as compared to the wind machines model A and model B.

Period	Model C (MJ m^{-2}/d)	Ideal Wind Machine (MJ m^{-2}/d)	Eff. of C (%)	% Eff. Increased Compared to A	% Eff. Increased Compared to B
Feb-Apr	1.13	2.02	56	14	10
May-Jul	0.93	1.53	61	22	19
Aug-Oct	0.95	1.63	58	16	14
Nov-Jan	2.47	5.42	46	2	1

During the Feb-Apr to Aug-Oct period, the mean wind speeds are substantially low. As a result, the wind machine Model C is operational for a much larger fraction of the total duration of available wind energy input than is Model B since it possesses a lower cut-in speed. On the other hand, during the Nov-Jan period, the mean wind speed considerably increases; it is almost twice the speeds during the Feb-Apr to Aug-Oct period. This increase enables the wind machine Model B to be more operational for a larger fraction of the total duration of available wind energy input compared to the first three periods. In addition, the higher rated power output of Model B also helps it to deliver more energy output, which resulted in an energy output delivery comparable to that of Model C.

Similarly, when we compare Model A to Model C, it can be seen that both models possess the same rated wind speeds at 14 m/s; but the rated power output per unit area of Model A is higher than that of Model C. Nevertheless, the energy output delivered by Model A is considerably lower than that of Model C. The same explanation as was given before can be given for the results of the comparison between Model A and Model C.

Consequently, we might conclude that the small amount of energy generated is attributable to the design characteristics of the wind machines Model A and B which are unsuitable for the wind regimes at the site.

A large wind machine which generally possesses a high rated power output also needs a high cut-in speed because of its high rotor inertia, whereas a small machine, even though it possesses a lower rated power output, requires a low cut-in speed. To achieve a large power output in low wind speed areas, a group of small wind machines (wind farming) designed for a low cut-in speed might be much more appropriate than a single, large stand-alone, high rated power output wind machine.

CONCLUSION

To evaluate the suitability of a commercial wind machine, proper matching between its designed operating wind condition and the frequency distribution of wind speeds at a site is the prime factor which must be considered. Other factors e.g. the machine's endurance and price, etc. are of secondary importance. A large wind machine with a high rated power generation may give a poor performance if it is operated under a wind regime that possesses a mean wind speed much lower than that for which it was originally intended. A high rated power generation generally is attributable to a high, cut-in wind speed, but this is rarely available in a location with low wind velocities. In the matching process, one has to compromise between the high power output of the wind machine and the low availability of high wind speeds needed to drive it.

In the tropics, where most developing countries are located, wind speeds are generally low. Wind machines designed for operating in wind 'rich' locations in the temperate zone may not be appropriate for these countries. A group of small wind machines, designed to be operated at low rated power outputs and low cut-in speeds, might be more suitable than a single, large, stand-alone wind machine with a high rated power output and a high cut-in speed.

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REFERENCES

1. Exell, R.H.B. (1981), *The Availability of Wind Energy in Thailand*, A.I.T. Research Report no. 134, pp. 10-17.
2. Moerup Industrial Windmill Co., *Technical Data Micon A/S*, Rander, Denmark.
3. Lysen, E.H. (1982), *Introduction to Wind Energy*, Steering Committee Wind Energy Developing Countries (SWD), Amersfoort, Chap. 8, pp. 185.