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Review Article

Potential of wind power for Thailand: an assessment

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Abstract: This paper reviews the potential for wind-power generated electricity in Thailand by means of a wide-ranging literature survey. Proposed application at a university campus is used as a case study to demonstrate that wind power is unlikely to be economically competitive where grid-connected electricity is available. The need for improved low wind speed turbine performance for Thai applications is highlighted by comparing the output of commercially available wind turbines with the characteristics of Thai wind; the challenges of improving low wind speed turbine performance are discussed. It is concluded that for Thailand in the foreseeable future the benefits of economic wind power electricity generation will probably be confined to small remote isolated installations including traditional applications.

Introduction

Energy extraction from the wind is philosophically appealing, having a negligible impact on the energy content of the resource itself and minimal, if any, physically destructive side effects. However, the energy intensity of the wind itself is generally low, as well as being quite variable, which means that for significant electrical power generation applications, large installations (i.e. combinations of turbine numbers and sizes) are required at favourable wind locations, which in turn are often remote from electrical load centres and from transmission grid networks.

While the demand on some of the other (non-renewable) resources required, e.g. construction materials, may be small, the additional infrastructure resources required for grid connected systems including backup power generation capacity can be large. Worldwide, there is currently more than about 48 GW of installed wind power generating capacity (representing about 0.6 % of total world electricity production, with capacity growing at around 20% pa), of which Thailand has less than 0.001%. However, for Thailand the economics of wind power installations may be unattractive and not competitive with other alternative energy sources now, or in the foreseeable future.

This paper was originally prepared as the result of an internal Joint Graduate School of Energy and Environment/ King Mongkut's University of Technology, Thonburi, (JGSEE/KMUTT) study on the potential for wind-power generated electricity for the Bangkhuntien Campus of KMUTT. It developed into a more general review of the wind power potential for Thailand. The paper has now been reviewed to determine whether the original findings should be modified in the light of developments in wind technology knowledge in the intervening 4 years.

A wind map has been produced for Thailand [1], which combines and updates the wind speed data previously available. Thailand experiences generally very low wind speeds with typically average speeds of not above 3 m/s. A Department of Energy Development and Promotion, Thailand (DEDP) report [2] produced around the same time as the wind map identifies in general terms the potential wind resource available for power generation as follows (Table 1):

Table 1. Wind energy potential in Thailand [1, 2]

Average wind speed and characteristic	Poor (<6m/s)	Fair (6-7m/s)	Good (7-8m/s)	Very Good (8-9m/s)	Excellent (>9m/s)
Land area (sq. km.)	477,157	37,337	748	13	0
% of Total land area	92.6	7.2	0.2	0	0
MW potential	NA	149,348	2,992	52	0

Note: For large wind turbines only. Potential MW assumes an average wind turbine density of 4MW per square kilometre and no exclusion for parks, urban or inaccessible areas. Wind speeds are for 65m height in the predominant land cover with no obstructions.

Those areas identified as having sufficiently high wind speeds for practical electricity power generation are for the most part inland areas presenting accessibility difficulties (as would be offshore sites) and therefore the potential for economic wind power generated electricity is probably considerably less than that indicated in the table.

The physical requirements for useful energy extraction remain as discussed in the original KMUTT study – the problem of the cubic relation between wind speed and power generating capacity remains. Currently available commercial wind turbines generally have the following characteristics:

- cut-in wind speed of 4 to 5 m/s (large turbines) and 3 to 4m/s (small)
- peak-power generation wind speed of $\pm$15 m/s (large) to $\pm$12 m/s (small)
- cut-out wind speed of ~25 m/s
- capability to safely withstand storm force winds of ~60 m/s +

An example of wind speed – power characteristics for the Bonus (Siemens) commercial range of wind turbines (Table 2) is given in Figure 1.

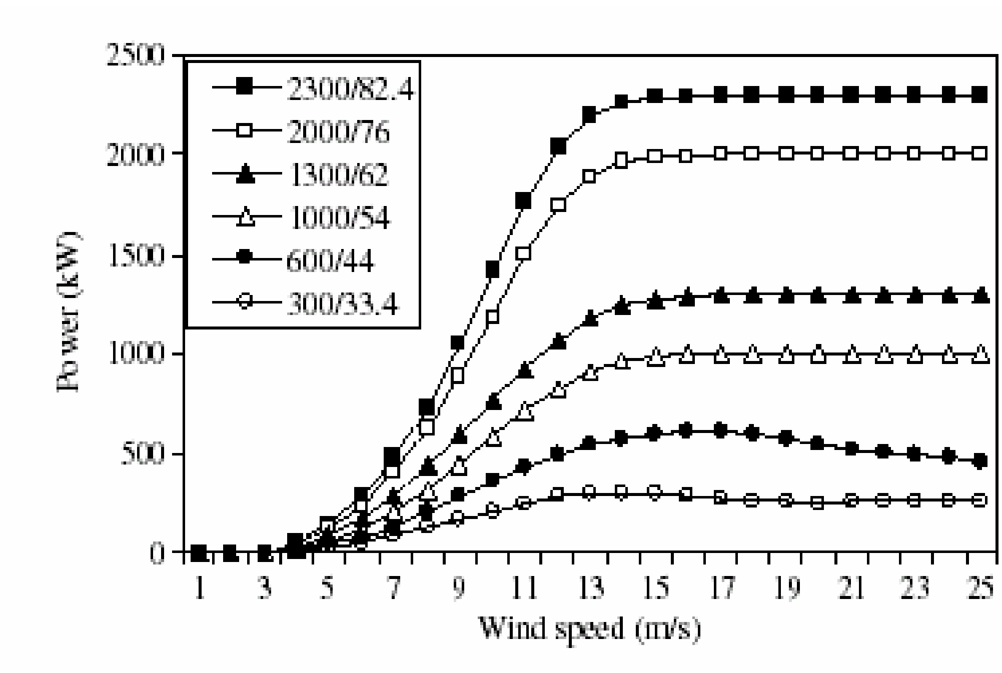

Figure 1. Turbine wind speed-power characteristics [3]

Table 2. Technical data of wind machines used in the analysis [3]

Wind machine	Cut in speed (m/s)	Cut out speed (m/s)	Rated speed (m/s)	Rated output (kW)	Hub height (m)	Rotor diameter (m)
Bonus 2300/82.4	3	25	15	2300	60	82.4
Bonus 2000/76	4	25	15	2000	60	76
Bonus 1300/62	4	25	14	1300	45	62
Bonus 1000/54	3	25	14	1000	45	54
Bonus 600/44	3	25	13	600	35	44
Bonus 300/33.4	3	25	13	300	30	33.4

The turbine performance profiles outlined above do not match well with the Thai monsoonal climate where near still air conditions alternate with high turbulence, giving overall very low average wind speeds. For reference, tables of wind power classes have been developed in the literature [4], as provided in the following examples (Table 3). It is evident from the current review that wind turbine and technology developments in the “low wind speed” zones refer to developments around class 3 – 4 wind speeds indicated in the above table. It seems that such developments are not at sufficiently low wind speeds to be of significant benefit to most potential Thai applications.

However, a detailed economic assessment of the significance of the wind resource potential identified in the DEDP report and table (Table 1) cited previously might be justified. Also, the potential for rural applications where the performance and economics of modern turbine types could be compared with traditional types in applications such as water pumping, battery charging, etc., particularly in remote areas, could usefully be investigated.

Finally, wind power globally is facing increasing obstacles, aside from economic or wind speed considerations. The situation of wind power in Australia, for example, and the climate for investment in this technology has recently become very uncertain as a result of the Australian Federal Government decisions not to increase support for MRET (Mandated Renewable Energy Target) by increasing its

Table 3. Wind power classes [4]

Elevation	10m		50m*	
Power class	Wind speed m/s	Power density W/m^2	Wind speed m/s	Power density W/m^2
1	0	0	0	0
	4.4	100	5.6	200
2				
	5.1	150	6.4	300
3				
	5.6	200	7.0	400
4				
	6.0	250	7.5	500
5				
	6.4	300	8.0	600
6				
	7.0	400	8.8	800
7				
	9.4	1000	11.9	2000

* Showing elevation effect based on 1/7 power law

level (the proposed/installed capacity required to meet the original 2% target is already virtually satisfied), and to suspend wind farm project approvals, even where State Government planning approval processes have been successfully negotiated and completed, on the basis of local community group objections on the grounds of landscape unsightliness and possible hazard to migratory birds. Thus Government regulation and attitude together with community consultation have become critical issues in Australia even where technology and wind conditions are favourable.

Case Study for KMUTT Bangkhuntien Campus

The following simple analysis is based on the premise that suitable low wind speed turbines were to become available for $US 1,000 per kW installed, and that the performance of the Cape Promthep (Phuket) 150 kW installation can be used as a "model" [5].

Assuming the annual mean wind speed at Bangkhuntien is 3.5 m/s, and taking the data [5] for the 150 kW installation delivering 1300 kWh/kW pa with a mean wind speed of 4.6 m/s (i.e., a 15% availability), and noting that wind power density is a function of wind speed cubed, then for Bangkhuntien, the availability would be approximately 7%, i.e. deliverable energy would be about 600 kWh/kW pa, i.e. $(3.5/4.6)^3$ x 1300.

So, if it is assumed that the annual electricity demand at Bangkhuntien is given by E kWh, then (E/600) x 1000 (US$) x 44 (Baht/US$) = Installation capital cost = 73E Baht, and the required installed capacity would be 73E/(44 x 1000) MW. Now, assuming a 20-year lifetime, and 10% pa of capital cost for operation and maintenance charges, and another 10% pa for interest charges, then the total lifetime costs would be 73E x (1 + 20 x 0.1 + 20 x 0.1) = 73E x 5 = 365E, and the cost per kWh delivered over the lifecycle would be 365E/20E = 18.25 Baht/kWh

The above analysis is very flexible and small changes in any of the assumptions, such as performance, operation/maintenance and financing costs, would make a large difference to the result. Also, since the original study, the exchange rate has varied considerably. It should be noted, however, that with the very intermittent nature of Thai wind, alternative standby power supplies and/or very large storage capability (perhaps by pumped storage?) would be required to ensure continuity of electricity supply. The costs associated with this requirement have not been factored in, but would need to be included in any accurate and complete analysis. The conclusion is thus that electricity costs from wind power generation would be about one order of magnitude greater than electricity purchased from the grid (at around 2.5 Baht/kWh).

Thailand's Wind Regime and Scenario

Wind speeds

From the Thailand Meteorological Department (Bangkok) and for the river mouth Pilot Station, monthly mean wind speeds taken from climatological data 1966 – 1995 are reported below (min. – max). The figures in { } are taken from "Solar and Wind Energy Potential Assessment of Thailand", a KMITT (now KMUTT) report from 1984 [7]:-

- Pilot Station: 3.4 – 5.6 m/s (max 60 m/s)
- Bangkok Metropolis: 1.2 – 2.5 m/s (max 45m/s) {2.37 m/s}
- Klong Toey: no data (max 29 m/s)
- Don Muang: 2 – 2.9 m/s (max 53 m/s) {3.13 m/s}
- From the above reference, the highest mean wind speeds reported for any location in Thailand are:
- Petchaburi: 4.9 m/s
- Pilot Station: 5.6 m/s
- The further data [6] shown below confirms the generally low wind speeds experienced in Thailand:
- Mean wind speed: < 5 m/s (range for Ubon 2.20 – 3.74 m/s; Haad Yai 3.6 – 4.35 m/s)
- Per cent calm period: a maximum of 48% (range from 35%) at Ubon, 93% at Haad Yai, and 35 – 46% at Phuket

Power densities

Exell [6] also includes power density information such as at Prachuapkhirikan, an annual mean of 92 W/m^2 (seasonal range 43 – 227), Songkhla 160 (80 – 240) and Phuket 168 (40 – 280).

From KMITT report [7], the following comments are made: "… wind speeds < 5m/s may be suitable for water pumping applications…"; "…wind speeds > 5m/s could meet a significant % of the energy needs of the country…", and also information given: "…that wind power densities > 500 W/m^2

are available over the ocean."; "…wind power densities > 200 W/m^2 are available over some limited land areas."

Note that available wind energy P_a/A (i.e. the power density x power coefficient = electricity production potential) is expressed by the power law:

P_a /A (W/m^2) = 0.5 x C_p (power coefficient) x p (air density) x V^3 (air speed)

A value for C_p = 0.4 has been assumed; this is the C_p achieved by most turbines running optimally. The maximum value obtainable is 0.593 (the Betz limit). An interactive model available at the Australian Wind Energy Association's (Auswea) website (see Appendix) for a range of turbine sizes at wind speeds probably in excess of those likely at Bangkhuntien has been run with the results as shown in Table 4.

Thus assuming C_p = 0.4 and taking p = 1.16 (from [6]), then P_a /A = 0.232 x V^3
which becomes, for the following wind speeds,

2 m/s: 1.86 W/m^2 (or, expressed as power density, 4.65)
4 m/s: 14.8 W/m^2 (37)
6 m/s: 50.1 W/m^2 (125)

These figures are in line with, or somewhat below, the mean power densities quoted for Thai locations above. They appear to be below the power densities needed for useful/economic electricity production.

Table 4. Auswea interactive wind energy model

Wind speed m/s	Rotor diameter m	Efficiency assumed (optimal ~ 40%)	Power output kW
5	10	40	10
5	50*	40	120 (~1 MW*)
5	5	40	2.5
3	10	50	2.7
4	20	40	20

* This is approximately the size of turbine being used to generate 1 MW under northern European conditions: thus for Thai wind conditions the power output would be around 10% of rated capacity (see also conclusions for Bangkhuntien campus analysis).

Selected quotes from relevant reports

The above statements are supported by a number of reports [5,8-15], from which the following comments have been extracted:

"…analysts…find insufficient wind resources…Thailand…" (p.31 of [8]);

"…it is recognised that there is no useful power output until about 10 mph (about 4.5 m/s)…" (p.5 of [8]);

"...little justification for any extensive promotion of wind power…" (p.2 of [5]);

"…as a rule of thumb…average annual wind speed between 5 and 7 m/s (is required) before it will be profitable to operate with wind energy schemes." [5];

"…where (an)…average wind speed above 5 – 6 m/s is never reached...avoid investment in wind turbine technology except for test and research…" (private communication received from Ramboll as a follow-up to [5]);

"….money better spent on other technologies…" (follow-up to [5]);

"…based on Phuket wind measurements…and a 600 kW wind turbine…payback period, 37 years." (p.2 of [5]);

"…average wind speed needed for economically viable projects (even with 'favourable' power purchase rates) = 8 m/s…" (p.179 of [9]);

"Wind generation – being reassessed" (p.16 of [10]);

"…In general, winds exceeding 5 m/s are required for cost effective application of small grid-connected wind machines, while wind-farms require wind speeds of 6 m/s…" [11];

"…In general, sites with a Wind Power Class rating of 4 or higher (i.e. > 5.6 m/s at 10 m elevation) are now preferred for large scale wind plants…" [11];

"…The average wind speed in Thailand is moderate to rather low, usually lower than 4 m/s." [12];

"…constraints affecting wind energy in Thailand:-

- absence of specific financing schemes designed to support wind energy development
- absence of grid for connection in many rural areas
- the lack of wind data which is sufficiently accurate
- industry standards to allow wind site identification
- some existing wind turbines not functioning
- low level of wind technology capacity" [13];

"…As of 2003, a total capacity of 1.5 MW of (wind-driven) water pumps and wind turbines delivering a total capacity of 0.388 MW have been installed mostly by the Electricity Authority of Thailand (EGAT) and DEDE. Currently the production cost of electricity for wind turbines is estimated to be between 0.11 and 0.13 US$/kWh." [14,15].

The Challenge of Low Wind Speed Regimes

Clearly the development of wind turbines capable of significant energy extraction at wind speeds below the normal low wind speed regime (i.e. < class 4 wind) is a major challenge. The US Department of Energy [4] states that the research goal of the Low Wind Speed Technology activity is "By 2012 to reduce the cost of electricity from large wind systems in Class 4 winds to 3 c/kWh for onshore systems or 5 c/kWh for offshore systems." Technology improvements are stated as being needed in the following points:

- Turbine rotor diameters must be larger to harvest the lower energy winds from a larger inflow area without increasing the cost of the rotor.
- Towers must be taller to take advantage of the increasing wind speed at greater heights.
- Generation equipment and power electronics must be more efficient to accommodate sustained light wind operation at lower power levels without increasing electrical system costs.

Under the title "Wind Energy Resource Potential", it is concluded that areas designated Class 4 or greater are suitable with advanced wind turbine technology under development today and that Class 3 may be suitable for future technology. Class 2 areas are marginal and Class 1 unsuitable for wind energy development.

The paper from which the following comments are drawn [16] addresses some of the issues involved. Comparison is made between the performance of commercially available machines and a postulated hypothetical low wind speed machine. The conclusion drawn is that "…To achieve a large power output in low wind speed areas, a group of small wind machines …designed for a low cut-in speed might be much more appropriate than a single, large stand-alone high rated power output wind machine.", and "… proper matching between its designed operating wind condition and the frequency distribution of wind speeds at a site is the prime factor…"

Substantial and ongoing R&D effort will be required to support low wind speed studies, including the development of appropriate test facilities such as that reported by Wahab and Tong [17] and investigations of low wind speed performance such as those by Wright and Wood [18]. Of course, for practical installations, the questions of capital and operating cost and service life have to be considered as well as sunk R&D costs. In fact, the technical and the economic aspects would need to be brought together along with social and political considerations for any successful application.

Overall Economics of Wind Power

There have been many cost comparisons between different electricity generating technologies. A recent example [19] provides the following data based on UK applications ('2004 pUK/kWh):

- Combined cycle gas turbine: 2.2
- Coal (all types): 2.5 – 3.2
- Nuclear power: 2.3
- Onshore wind: 3.7 (rising to 5.4 allowing for back up generating capacity)
- Offshore wind: 5.5 (rising to 7.2 allowing for back up)
- Wave & marine: 6.6
- Biomass: 6.8

An article in Power Generation World [20] cited wind power generation costs at US$/kWh 0.03 – 0.06 compared to approximately US$/kWh 0.04 for fossil fuels while other reports [14,15] give the wind power generation cost between 0.11 – 0.13 US$/kWh.

In an article in the National Geographic Magazine (2005) (see Appendix for details), approximate power costs in USc/kWh are given as: coal – 5, natural gas – 5.5, wind – 6, nuclear – 7, solar – 22. Another source [21] provides some comparative information on operating, maintenance and fuel costs in USc/kWh (1985) for different electricity generating technologies as follows: wind – 1, coal – 2.3, nuclear – 1.9, gas – 4.2, oil – 5.3. Even if these figures were only very approximate and have changed with the passage of time, they do suggest that the running costs of wind turbines are not insignificant.

Comparisons of generating costs from published data can be difficult because it is not always clear whether the full life cycle costing has been undertaken and all relevant costs have been included. For example, it is not known whether the following have been included in any analysis:

- planning approval and design (including R&D costs where relevant),
- construction costs (including off-site works where required, e.g. strengthening transmission systems, providing for additional generating capacity, etc.),

- operating costs including fuel sourcing, supply and waste disposal, plant maintenance and refurbishment, etc.,
- at the end of service life, the total cost of decommissioning and storage and disposal where required,
- all environmental costs, e.g. climate levies (carbon taxes or credits), land remediation, etc.,
- the cost of financing the necessary investments.

These costs are very site, region and date specific.

Commercially Available Wind Turbine Generator Technology

Wind turbines are commercially available across a very wide range of generator outputs, from a few watts to several megawatts. In this paper there have been several references to data taken from the webpages of wind turbine manufacturers. A listing of a selection of these suppliers is included in the Appendix. Also included is a reference to a provider of software suitable as an aid to designing wind turbine generating systems as well as to providers of more general wind power information.

Conclusions

It would appear from this investigation that there is no justification for investing effort on wind power projects for grid connected electricity production at any scale, and no justification for such an electricity generating installation at the Bangkhuntien campus. There may be some justification for continuing to work on projects intended for remote area applications, where mean wind speeds are at the upper end of reported data for Thailand (e.g. 4 –5 m/s), for example for water pumping application.

Thus at Bangkhuntien it could be recommended that studies continue along the path of existing work being undertaken of wind turbines suitable for intermittent loads such as water pumping operating under low wind speed conditions. This work might be immediately applicable to situations such as that at the salt farms to the south-west of Bangkhuntien where traditional windmills are still in use, or for prawn farms.

It should be mentioned that while wind systems may not be currently economically or technically attractive, nonetheless it would be useful for Thailand to have technical capability in this area (as provided by the Cape Promthep installation) and for potential hybrid situations, such as at remote national parks. A continuing watching brief on overseas technology would be appropriate not only to wind turbine developments for low wind speed conditions, but also to developments in such associated equipment as batteries, e.g. versatile systems based on technology similar to fuel cell technology which could simplify the output electrical power conditioning constraints for wind turbines and which could well make some difference to viability.

However, it would be of some concern, based on the low wind potential noted above and in the previous reports from which comments have been drawn, if the statements reported in the Bangkok Post (Business Pages) of late December 2001 were accurate, i.e. that "…energy conservation plan … key projects … promoting … wind power …" If true, this would appear to be a misallocation of resources.

The correspondence of January 8th and 13th, 2002 in the same newspaper together with an article profiling the EGAT Governor's views of 21st January, 2002 all covered the same ground, with the latter drawing a similar conclusion to that of the authors.

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21. "Wind turbine technology", Report, JGSEE Library, call no. TJ 828.W763), **1994**, p. 208.

Appendix

The following are supplier listings but are not comprehensive:

1. Wind power software and general information
   - Australian Wind Energy Association, www.auswea.com.au , includes a model for power generation estimates (2002).
   - "Wind Turbine Technology Briefing Notes", The British Wind Energy Association, 2006, www.bwea.com
   - American Wind Energy Association, www.awea.org
   - HOMER micropower optimization model as an aid to off-grid and grid connected systems, National Renewable Energy Laboratory – NREL, US, www.nrel/gov/homer (see also the model Windographer @ www.mistaya.ca/windographer)
   - National Geographic Magazine, August, 2005: p2 "Powering the Future" (www.nationalgeographic/magazine/0508)
   - BP Global Energy Review – World wind energy and other data at end 2004, (www.bp.com/sectiongenericarticle)

2. Wind turbine hardware suppliers
   - Wind Energy Businesses in the World – from Source Guides – for detailed listings of suppliers by country www.energy.sourceguides.com/businesses

- Siemens Wind Power (previously Bonus @ www.bonus.dk): 22 kW to 2.3 MW range: (5800 turbines in operation – installed capacity 4500 MW) www.powergeneration.siemens.com/en/windpower
- Swift Silent Rooftop Wind Energy System, UK, 1.5 kW, www.renewabledevices.com
- NEG-MICON: (7,400 turbines in operation – 23% of world generating capacity – 16% annual growth rate in MW installed – future offshore installations in 3 – 5 MW range), Denmark, www.neg-micon.dk
- US Wind Turbine, www.uswindturbine.com, 1kW – 5 MW range
- Windstream Power Systems, US. (www.windstreampower.com), 0.1 kW
- Travere Aerogenerateurs, France, 0.3 kW – 12.5 kW range, www.travere.com

3. Information on the wind power situation in Thailand

- Electricity Authority of Thailand – www.egat.or.th - which gives details of the Cape Promthep, Phuket wind power installation – turbines 22 – 150 kW (as at 2002)