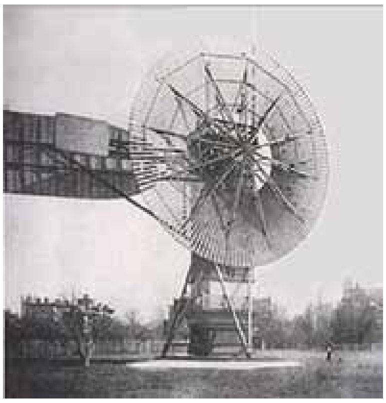
Wind Energy: General

energy
Department:
Energy
REPUBLIC OF SOUTH AFRICA

EMBASSY OF DENMARK

POWERED BY WIND

History

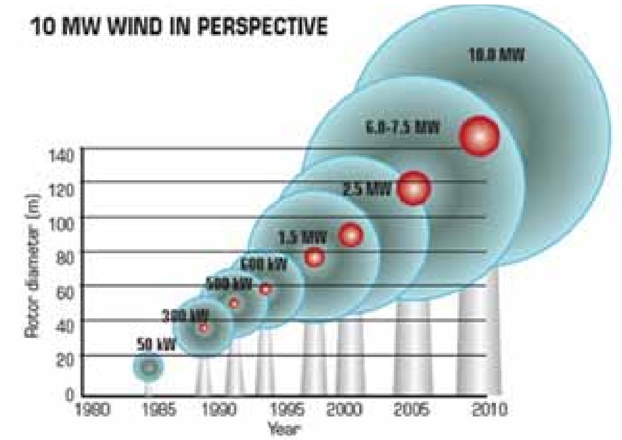


Humans have been using wind power since ancient times to propel sailboats and sailing ships. The wind wheel of Heron of Alexandria marks one of the first known instances of wind powering a machine in history[1,2]. The first electricity generating wind turbine was a battery charging machine installed in July 1887 by Scottish academic, James Blyth to light his holiday home in Marykirk, Scotland[3]. Some months later American inventor Charles F. Brush built the first automatically operated wind turbine for electricity production in Cleveland, Ohio[3]. In the 1890s, Danish scientist and inventor Poul la Cour constructed wind turbines to generate electricity, which was then used to produce hydrogen[4]. The Smith-Putnam wind turbine was the first megawatt-class wind turbine which was synchronized to a utility grid in Vermont in 1941.

Siemens and Vestas are the leading turbine suppliers for offshore wind power. Dong Energy, Vattenfall and E.on are the leading offshore operators[5]. As of October 2010, 3.16 GW of offshore wind power capacity was operational, mainly in Northern Europe.

Fig. 1 The first automatically operated wind turbine, built in Cleveland in 1887 by Charles F. Brush. It was 60 feet (18 m) tall, weighed 4 tons (3.6 metric tonnes) and powered a 12kW generator[6].

Fig 2 It is easier to appreciate the size of new 10-MW turbines with comparisons to previous generations. The Clipper Windpower Britannia turbines, for example, will have towers about as high as 50-storey buildings[7].



As of May 2009, 80 countries around the world use wind power on a commercial basis[8] with China taking the lead at 42,287 MW (March 2011[9,10]). The total capacity of wind installed by 2010 was 194,400 MW[11]. Wind power accounts for approximately 24% of electricity use in Denmark, 16.4% in Spain[12], 15% in Portugal, 10% in the Republic of Ireland, and 9½% in Germany. South Africa's first commercial wind farm, Darling Wind Farm (5.2 MW), was commissioned in May 2008.

Growth trends

Despite constraints facing supply chains for wind turbines, the annual market for wind continued to increase at an estimated rate of 37%, following 32% growth in 2006. In terms of economic value, the wind energy sector has become one of the key players in the energy markets, with the total value of new generating equipment installed in 2007 reaching €25 billion, or US$36 billion[13].

Over the past five years, the average growth in new installations has been 27.6% per annum. In the forecast to 2013 the expected average annual growth rate is 15.7%[13,14]. More than 200 GW of new wind power capacity could come online before the end of 2013. Wind power market penetration is expected to reach 3.35% by 2013 and 8% by 2018[13,14].

Wind turbine types

There are primarily three types of wind turbines:

1) The Horizontal Axis Wind Turbine (HAWT),
2) The Vertical Axis Wind Turbine (VAWT), and
3) Other variations.

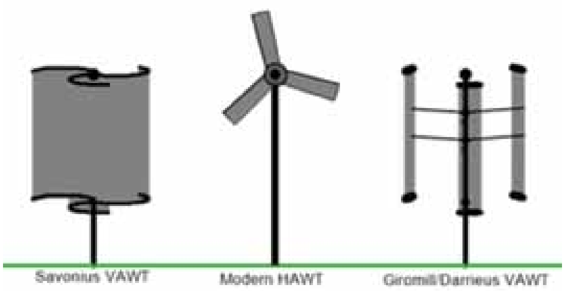


Fig 3. Vertical Axis Wind Turbine (VAWT), Horizontal Axis Wind Turbine (HAWT) (source Wikipedia)

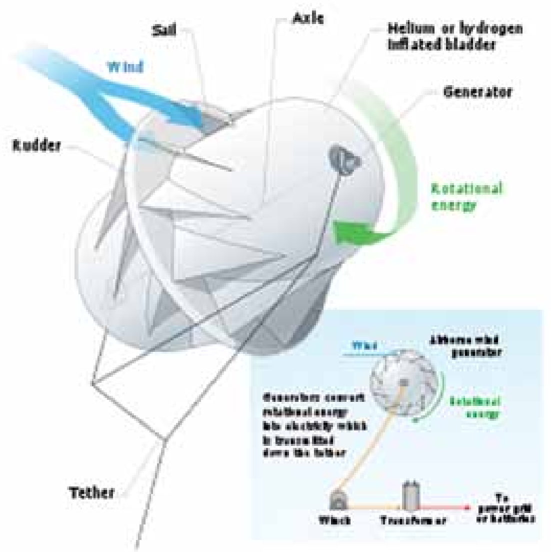
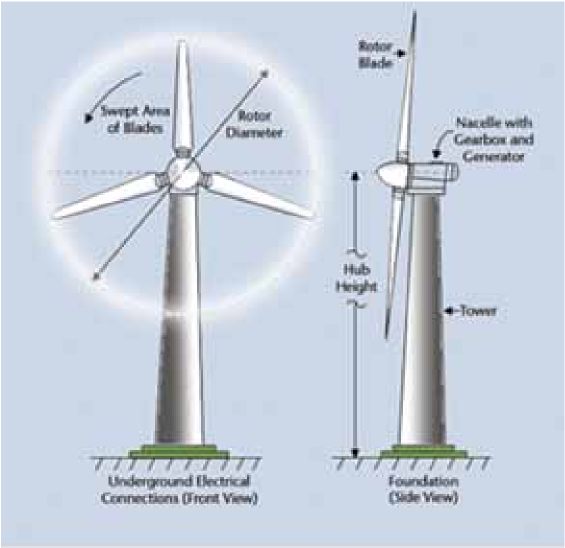


Fig 4. Airborne wind generator of Savonius style (source Wikipedia)



Drawing of the rotor and blades of a wind turbine, courtesy of ESN

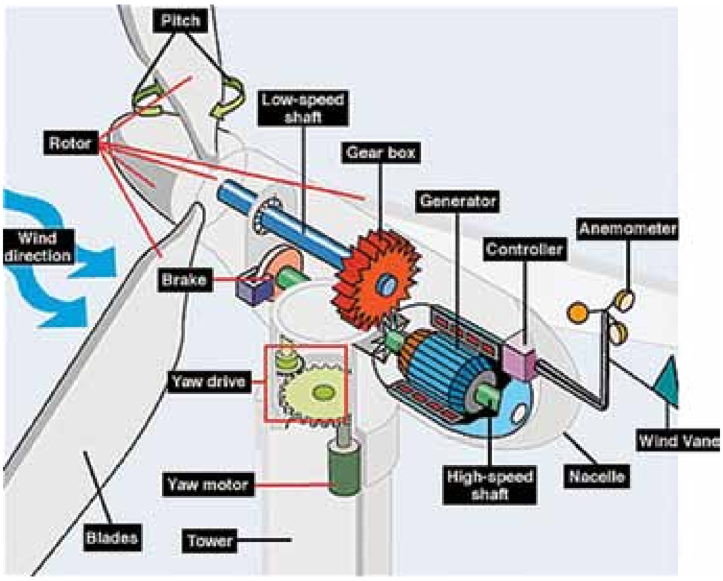


Fig 5. Components of a typical Horizontal Axis Wind Turbine (HAWT)

Wind turbine power generation

A wind turbine extracts and converts the energy in wind into electrical energy via wind that flows over and causes lift of the wind turbine blades that turn an electricity generator. The power of a wind turbine can be described by the following equation:

$$P(W) = c_p 1/2 \rho A v^3 \ldots\ldots\ldots\ldots 1$$

P power in watts, cp power coefficient, ρ air density (kg/m^3), A swept area of blades (m^2), v wind speed (m/s)

From above equation it follows that:

- Power of a wind turbine increases with cube of the wind speed v^3
- Power of a wind turbine is proportional to the swept area A of the blades, hence increases quadratically with the rotor diameter D ($A=\pi.D^2/_4$)

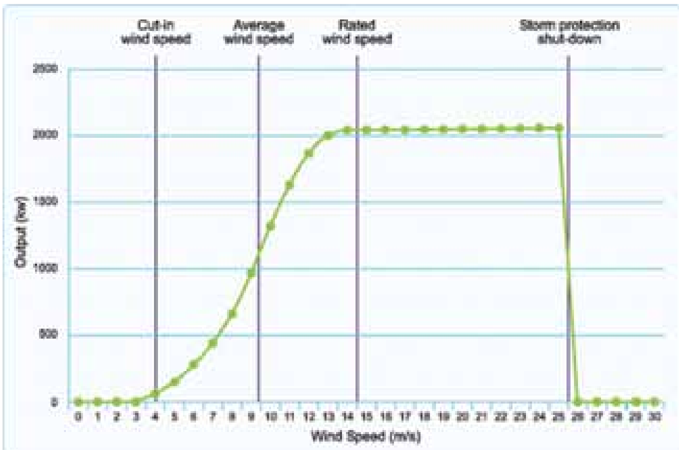


Fig 6 Typical Wind Turbine Power Curve[15]

The theoretical wind energy extraction limit of a HAWT is 59,36% (Betz law) (meaning the theoretical maximum energy in the wind that can be extracted by a HAWT is 59,36%). In general, also taking into account conversion losses for example, the power coefficient cp of a wind turbine is in the order of 30 to 40%[16].

The availability of modern HAWT is typically 98% and more. This is the capability of the wind turbine to operate when the wind is blowing at or above the turbine's cut in wind speed and when the wind turbine is not undergoing maintenance.

The capacity factor of a power plant is the ratio of the electrical energy produced in a given period of time to the electrical energy that could have been produced at continuous maximum power operation during the same period.

Global wind turbine capacity factor statistics[17]:
Spain 24.6% *Germany 16%*
Denmark 24% *Sweden 19%*

Capacity factor (CF) is very useful, but is often mistaken for the total amount of time a wind turbine operates (that is, if the CF is 25%, people think the turbine is only producing electricity 25% of the time). In reality, at most sites, it will be generating at a much higher percentage of the time (availability of 98% and more), but at less than its peak output level[18] (rated wind speed).

1 A.G. Drachmann, "Heron's Windmill", Centaurus, 7 (1961), pp. 145–151
2 Dietrich Lohrmann, "Von der östlichen zur westlichen Windmühle", Archiv für Kulturgeschichte, Vol. 77, Issue 1 (1995), pp. 1–30 (10f.)
3 "James Blyth". Oxford Dictionary of National Biography. Oxford University Press. Retrieved 2009-10-09.
4 Price, Trevor J (3 May 2005). "James Blyth - Britain's first modern wind power engineer". Wind Engineering 29 (3): 191–200.
5 Madsen & Krogsgaard. Offshore Wind Power 2010 BTM Consult, 22 November 2010. Retrieved: 22 November 2010.
6 A Wind Energy Pioneer: Charles F. Brush. Danish Wind Industry Association. Retrieved 2008-12-28.
7 http://eetweb.com/wind/wind-turbines-go-supersized-20091001/
8 "Wind Power Increase in 2008 Exceeds 10-year Average Growth Rate". Worldwatch.org. Retrieved 2010-08-29.
9 Global Wind Energy Council
10 Wald, Matthew L. (January 11, 2011). "China's Galloping Wind Market". The New York Times.
11 Global wind energy council
12 EWEA Annual Statistics 2010
13 "BTM Forecasts 340-GW of Wind Energy by 2013". Renewableenergyworld.com. 2009-03-27
14 BTM Consult (2009). International Wind Energy Development World Market Update 2009
15 http://www.pfr.co.uk/standfordhill/15/Wind-Power/119/Capacity-Factor/
16 Wind Resource Assessment in Australia – A Planners Guide, CSIRO, V1.1, October 2003
17 Windstats newsletter, volume 19 number 2 (Spring 2006)
18 http://lightbucket.wordpress.com/2008/03/13/the-capacity-factor-of-wind-power/

Wind resource assessment

Applying equation 1, a difference of 5% in wind speed (v) will result in a difference of 15% power (P) output of the wind turbine. It is therefore of the utmost importance that the wind data be accurate, representative, reliable and measured at or as near the wind turbine hub height (hub connecting blades) as possible. The height of the top wind speed measurement shall be at least two thirds of the planned hub height[19]. A minimum of one year of on-site wind data is typically required by financial institutions. Only reliable, calibrated sensors and instrumentation should be used. Appropriate arrangement of instruments on the measurement mast is important for accurate data capturing. In particular, the anemometer shall be located to minimize flow distortions, especially from mast and boom influences[20]. The South African Wind Atlas Project (WASA) wind measurement mast arrangement, instrument summary and mast site information can be found on the following websites:
http://www.wasa.csir.co.za/ and
http://wasadata.csir.co.za/wasa1/WASAData.

The output of a dedicated on-site wind measurement program can be graphically illustrated as a wind rose for that site. The wind rose is a graphic illustration of the wind conditions, direction, speed and frequency over the wind measurement period at a specific location. The length of each 'spoke' around the circle is related to the frequency of time that the wind blows from a particular direction. Each concentric circle represents a different frequency, emanating from zero at the center to increasing frequencies at the outer circles.

By making use of the wind rose in Figure 7, as well as topographical and terrain data of the wind measurement mast site, an Observational Wind Atlas can be constructed for the site. By combining the Observational Wind Atlas with a wind turbine power curve as represented in Figure 6, the power output of the wind turbine, wind farm and wind resource map Figure 8 (AEP, Annual Estimated Power production, GWh) can be calculated for that site and immediate surroundings.

Meso and micro scale modeling

Meso scale models, which were developed for numerical weather prediction and combined with micro scale models, are increasingly used, refined, and validated in the calculation and development of (numerical) wind atlases in Egypt, Canada, the United States of America and China, for example. It has been shown that, by utilizing appropriate meso and micro scale models, it is possible to calculate and develop wind atlases in half the time and at a lesser cost of making traditional (observational) wind atlas based on physical wind monitoring. This is made possible because the meso scale model uses a variety of global, geophysical and meteorological databases, such as the reanalysis database which is a gridded historical weather data produced by the United States' National Centers for Environmental Prediction (NCEP) and Atmospheric Research (NCAR). Furthermore, by combining the meso scale model with the micro scale model, and taking into account local topography and roughness profile, for example, regional wind climates can be calculated and presented in a numerical wind atlas. The standard error in mean wind speed for these models is usually 7% or less once uncertainties in the data are removed.

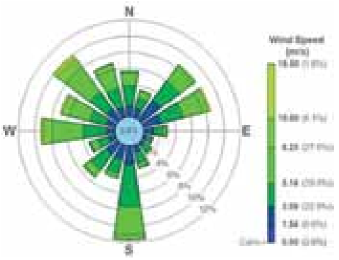


Fig 7. Wind Rose (source: Wikipedia)

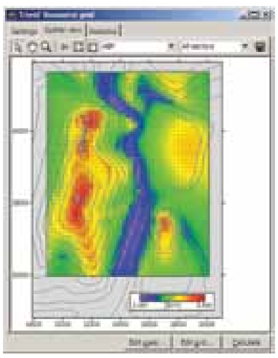


Fig 8. Sample Wind Resource map[21]

Application of the numerical wind atlas saves time and money in calculating local wind climates that can be used to predict, without physical wind measurements, key parameters such as the wind speed, frequency, direction, estimated power output and wind farm layout at any site covered by the numerical wind atlas.

By integrating (GIS) the numerical wind atlas and data from electricity networks, roads, towns, and environmentally sensitive areas, for example, it enables decision-makers, developers and financiers to identify upfront potential viable wind 'hot spots' in reasonable time and before lengthy and costly wind measurements needs to be done,.

By 'downscaling' (micro scale) the meso scale wind atlas to higher resolution it can be used to explore these wind 'hot spots' for feasibility studies, motivation of bankable projects and for national resource planning.

	National planning	Regional planning	Local planning, wind farm siting	WF layout & micro-siting
Model type	Mesoscale	Mesoscale	Meso- and microscale	Meso- and microscale
Domain size	500-1000 km	100-500 km	20-100 km	10-20 km
Map resolution	5-10 km	1-5 km	10-100 m	1-10 m
Wind data	NCEP/NCAR reanalysis data	NCEP/NCAR reanalysis data	NCEP/NCAR + met. stations	Dedicated met. stations
Verification	Representative met. stations	Representative met. stations	Dedicated met. stations	Dedicated met. stations
Uncertainty on mean speed *U*	10-30%	10-20%	5-15%	1-10%

Wind Resource Assessment Summary (Source: Riso, DTU)

Conclusion

The application of wind energy for electricity generation has come a long way, and wind turbine theory and technology are well understood and commercialized. By making use of state of the art wind resource assessment methods, national, regional and local wind resource planning can be done and viable wind 'hot spots' can be identified and developed.

19 Measnet, Evaluation of Site Specific Wind Conditions, V1, November 2009
20 IEC61400-12-1 Power performance measurements of electricity producing wind turbines
21 Getting Started with WAsP 9, Risø-I-2571(EN)