EXPLOITING WIND POWER IN ANTARCTICA

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Abstract

In the 1950s and 60s, the remote and inhospitable Antarctic region saw the establishment of many scientific stations. These scientific stations require highly reliable continuous power to ensure both the continuity of scientific activities and a suitable level of comfort for the expeditioners.

Engineers have always turned their minds to the use of renewable energy at the stations and, because of the high winds generally experienced, wind power was always felt to be the most promising solution. But the early expeditions encountered reliability problems with wind turbines and found that conventional generator sets and boilers were the only satisfactory, practical answer to the reliable provision of the energy required at the stations. Although continually improved, the present energy systems still rely on the same basic principles.

In recent times, environmental and logistic concerns have provided an incentive for a move away from the reliance on imported fuels to using renewables. Preliminary studies conducted in the framework of a cooperative French-Australian Project have identified wind power as the most promising solution for immediate implementation at the two nations' stations.

This paper outlines the wind characteristics at several stations and, after discussing the availability of suitable wind turbines, looks at the power generation potential of selected turbines at these stations.

Résumé

Dans les années 1950 et 60, l'inhospitalière et reculée région Antarctique vit l'établissement de nombreuses stations scientifiques. Ces stations requièrent une fourniture en énergie hautement fiable et continue pour assurer à la fois la continuité des activités scientifiques et un niveau de confort approprié pour le personnel.

Les ingénieurs ont toujours tourné leurs esprits vers l'utilisation d'énergies renouvelables dans les stations et, en raison des forts vents généralement rencontrés, l'énergie éolienne fut toujours pressentie comme la solution la plus prometteuse. Mais les premières expéditions rencontrèrent des problèmes de fiabilité avec les éoliennes et trouvèrent que groupes électrogènes et chaudières conventionnels étaient les seules réponses pratiques et satisfaisantes à la fourniture fiable en énergie requise par les stations. Bien que continuellement améliorés, les systèmes actuels reposent toujours sur les mêmes principes de base.

Récemment, des soucis environnementaux et logistiques ont fourni une nouvelle motivation pour rendre les stations moins tributaires des carburants importés par une meilleure utilisation des énergies renouvelables. Des études préliminaires menées dans le cadre d'un projet Franco-Australien ont identifié l'énergie éolienne comme étant la solution la plus prometteuse pour une mise en oeuvre immédiate dans les stations de ces deux nations.

Cet exposé esquisse les caractéristiques du vent à plusieurs stations et, après avoir débattu la disponibilité d'éoliennes appropriées, examine le potentiel de production d'une sélection d'éoliennes à ces stations.

1. INTRODUCTION

The "exploration" of the remote and inhospitable Antarctic region up to the first half of this century was followed by the establishment of stations to study and collect weather data, geological, geomagnetic and biological data. The International Geophysical Year (IGY, 1957-58) saw the founding of an international, coordinated network of scientific stations in the high southern latitudes on and around the Antarctic continent. The unprecedented cooperation on which the IGY activities were based, lead to the Antarctic Treaty and to the permanent operation of a network of scientific stations. The majority of the current stations are spread along the Antarctic coast while most of the rest are on Sub-Antarctic islands. Only very few inland stations are operated. All these scientific stations require highly reliable continuous power to ensure both the continuity of scientific activities and a suitable level of comfort for the expeditioners.

Engineers have always turned their minds to the use of renewable energy at the stations and, because of the high winds generally experienced, wind power was always felt to be the most promising solution. But, the early expeditions encountered reliability problems with wind turbines and found that conventional generator sets and boilers were the only satisfactory, practical answer to the reliable provision of the energy required at the stations. Although continually improved, the present energy systems still rely on the same basic principles. The primary power supply is diesel fuel based, with generator sets providing AC power as well as heat through jacket-water and exhaust heat recovery systems, supplemented by conventional boilers. This has the advantage of relying on well known highly reliable technology. The compactness of such systems is also an advantage at sites where space is scarce and where station installations have to share the area with local wildlife.

In addition to the atmospheric pollution caused by the exhaust gases, the operation of diesel power systems holds an inherent risk of fuel spills, notably during ship-to-shore transfers which can often take place under difficult circumstances. Sophisticated, expensive marine science vessels with tight schedules and numerous scientists on board can often be forced to spend several unproductive days at stations, while critical station fuel is transferred ashore. The absolute reliance of the station on imported fuel can exert pressure on logistic operations, and unexpected events, such as technical breakdowns or natural phenomena (storms, heavy ice cover), can threaten the closure or downgrading of station scientific activities and ultimately jeopardise the safety of expeditioners. This can be despite the existence of safety stocks and depots of fuel.

The pressure then is on to move away from the reliance on imported and environmentally unfriendly fuels by using renewables. Preliminary studies conducted in the framework of a cooperative French-Australian Project have identified wind power as the most promising solution for immediate implementation at the two nations' stations (Guichard, 1994a,b).

2. WIND CHARACTERISTICS AT STATION SITES

2.1 General conditions

Remote Antarctic stations generally have to face difficult wind conditions. Typical average wind speeds at coastal sites range from 5 to 10 m/s with a high frequency of strong winds and extreme top speeds where katabatic winds rush down the slopes of the ice cap. The area subject to the highest katabatic winds is the portion of the East Antarctic coast directly south of Tasmania. The average wind speed recorded by Douglas Mawson's Australasian Antarctic Expedition over 2 years (1912-13) at Cape Denison (66°59'S, 142°39'E) was 19.0 m/s, while at nearby Port-Martin (66°49'S, 141°24'E) Expéditions Polaires Françaises recorded over 1950-51 an average wind speed of 16.9 m/s (Parish, 1981). A record monthly average of 29.1 m/s was observed at Port-Martin in March 1951, which is three times higher than the highest monthly average recorded at Lerwick in the Shetland Islands, a place famous for its storms (Pettre & Andre, 1990). A record 2 minute average of 90 m/s has been experienced at Dumont d'Urville (66°40'S, 140°01'E) (Payan & Periard, 1991).

The Sub-Antarctic islands typically experience severe storms, with frequent gusty winds from 5 to 15 m/s, generally from the West. Top wind speeds are also very high, with for example a highest gust of 80m/s recorded at Kerguelen Island (49°21'S, 70°14'E) in August 1970 (Météo France data), but temperatures are relatively mild. On the other hand, inland Antarctic sites are in the high pressure zone sitting on the Antarctic Ice Cap and face extremely low temperatures but moderate winds. For example, at South Pole, the minimum temperature recorded is -82.8°C with an average of -49°C, but the maximum wind gust is of only 24.2m/s for an average wind speed of 5.4 m/s (Ferraro, pers. comm.).

Table 1 summarises temperature and wind conditions at French and Australian Stations plus some other selected Antarctic and Sub-Antarctic sites. Two Tasmanian sites are included for comparison. The table demonstrates how <u>the average wind speeds encountered in Antarctic coastal and sub-Antarctic sites (5 to 19 m/s) are promising for wind power generation, but the maximum wind gusts (51 to over 90 m/s) threaten to destroy the turbines</u>.

2.2 Wind Speed Frequency Distribution

The preliminary assessments of wind power potential presented in Guichard (1994b) were based exclusively on average wind speeds by assuming the wind speed frequency distributions to be a Weibull distribution of factor 2. Extensive data sets obtained since have allowed actual wind speed (at 10m height) frequency distributions to be determined for several stations. More stations will be added as data sets come in, and frequency distributions will be adjusted to Weibull distributions for easiest assessment of wind potential. The frequency distributions shown here were calculated by separating wind speeds into 20 bins of 5 knots range between zero and 100 knots (non inclusive), plus the zero value and the values equal to or larger than 100 knots.

Figure 1 outlines the shape of the frequency distributions obtained, at Casey, Mawson and Davis for all complete years of data available, and at Macquarie Island for a 5 year period (1990-94). Hobart and Maatsuyker Island in Tasmania (also for 1990-94) were added for comparison. Casey and Davis, like Hobart, show a sharp peak located between 0 and 10 m/s while Mawson and Macquarie, like Maatsuyker, have a larger spread of speeds from 0 to 20 m/s.

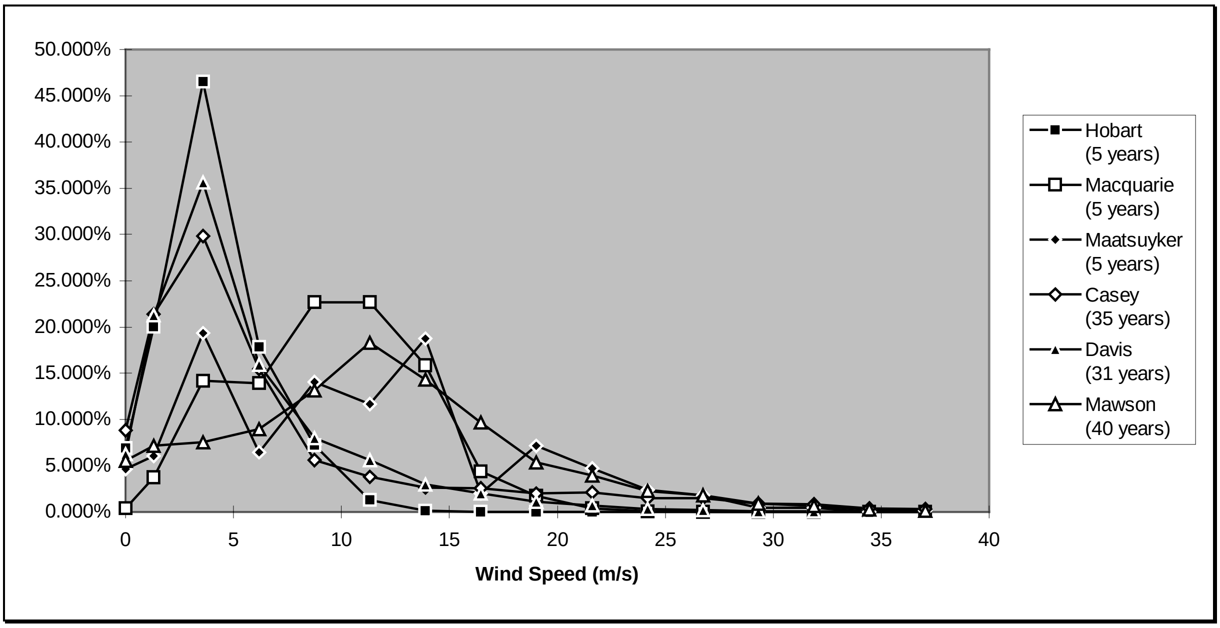

Figure 1: Wind Speed Frequency Distribution at Selected Locations

Air Temperature and Wind Speed Summary at selected locations (Antarctic, Sub-Antarctic & Oceanic, Tasmania) AG/Oct95						Air temperature (Deg. C)					Wind Speed (m/s)						
						Average			Minimum	Maximum	Average		Maximum			Highest	Lowest
						from 3h measures	from daily (Min+Max)/2	(Mean Min + Mean Max)/2	from spot measures	from spot measures	from Daily Run	from 3h 10minAv	from 3h 10minAv	from spot 2min av.	from spot Inst. Gust	Monthly Average	Monthly Average
Location	Data Availability	Comment	Lat	Long	Elev.	(1)	(5)	(6)	(1)	(1)		(2)	(2)	(3)	(4)	(2)	(2)
Casey	from 1960	Antarctic, Coastal	66°17S	110°32E	12 m			(a) -8.85	(a) -41.0	(a) 9.2	(a) 6.77	(h) 6.5	(h) 50.9		(a) 80.76		
Davis	1957-64, then from 69	Antarctic, Coastal	68°35S	77°58E	12 m			(a) -10.25	(a) -40.0	(a) 13.0	(a) 4.88	(h) 5.1	(h) 47.3		(a) 57.1		
Mawson	from 1954	Antarctic, Coastal	67°36S	62°52E	8 m			(a) -11.25	(a) -36.0	(a) 10.6	(a) 10.66	(h) 11.2	(h) 50.9		(a) 68.9		
Dumont d'Urville	from 1956	Antarctic, Coastal	66°40S	140°01E	43 m		(e) -10.6					(e) 10.0		(k) 90		(e) 19.5	(e) 5.0
Port Martin	1950-51	Antarctic, Coastal	66°49S	141°24E	20 m							(m) 16.9				(n) 29.1	
Cape Denison	1912-13	Antarctic, Coastal	66°59S	142°39E	25 m							(m) 19.0					
South Pole	from 1957	Antarctic, Inland	90°00S	-	2 835 m	(f) -49			(f) -82.8	(f) -13.6		(f)? 5.4			(f)? 24.2		
Dome C	1980-82 & 84-92	Antarctic, Inland	74°40S	124°10E	3 200 m	(g)? -50.8			(g)? -84.6			(g)? 2.8			(g)? 17		
Macquarie	from 1948	Island, Sub-Antarctic	54°30S	158°56E	6 m			(a) 4.75	(a) -8.9	(a) 14.4	(a) 7.93	(i) 9.4	(i) 28.8		(a) 51.4		
Kerguelen	from 1951	Island, Sub-Antarctic	49°21S	70°14E	29 m	(b) 4.7		(b) 4.75	(b) -9.4	(b) 25.8		(b) 9.8			(b) 80		
Crozet	from 1956	Island, Sub-Antarctic	46°26S	51°52E	142 m			(c) 5.6	(c) -4.0	(c) 21.9		(d) 10.7			(d) 70	(d) 16.6	(d) 7.5
Amsterdam	from 1950	Island, Oceanic	37°50S	77°34E	28 m	(b) 13.8		(b) 13.9	(b) 1.8	(b) 25.2		(b) 7.4			(b) 56		
Hobart	?	Tasmania	42°53S	147°20E	55 m			(a) 12.5	(a) -2.8	(a) 40.8	(a) 3.14	(i) 4.0	(i) 16.5		(a) 41.67		
Maatsuyker	from 1891	Island off Tasmania	43°39S	146°16E	147 m							(i) 10.3	(i) 41.2				

Notes:

(1) Obtained from the set of standard 3hourly (3h) Temperature measures
(instantaneous measures taken every 3 hours, usually at 00h, 03h, 06h...UTC)
(2) Obtained from the set of standard 3hourly 10minute Average (3h 10minAv) Wind Speed measures
(averages over the previous 10 minutes, taken every 3 hours, usually at 00h, 03h, 06h...UTC)
(3) Highest 2minutes average over full time (that is, not restricted to set of standard measures)
(4) Highest instaneous gust over full time (that is, not restricted to set of standard measures)
(5) Obtained by averaging of all the daily "(Absolute Daily Temp. Maximum+Absolute Daily Temp. Minimum)/2"
(6) Equals "(Mean of all Absolute Daily Minimums + Mean of all Absolute Daily Maximums)/2"

(?) Method used to measure/process data not confirmed

(a) in Australian Bureau of Meteorology (MetBureau) Summary Data Sheets for all years of record to the end of 1991
(b) in Météo France Summary Data Sheets for all years of record to the end of 1993
(c) computed from Météo France Summary Data Sheets for individual years 1989,90,91,92,93
(d) in Météo France Summary Tables of Monthly Mean Wind Speed and Monthly Maximum Gust for 1966 to 1990
(e) computed from Météo France Summary Tables of Monthly Mean Wind Speed and Temperature for 1956 to 92
(f) obtained from Ferraro, pers. com., originates from U.S. Meteorology data
(g) computed from AWS data 1980-82 & 84-92 found in Keller et al., 1994 and previous years
(h) computed from MetBureau standard 3hourly data for all complete years available
(Casey: 61-94, Davis: 58-63 & 70-94, Mawson: 55-94)
(i) computed from MetBureau standard 3hourly data for 5 complete years (1990-94)
(k) in Payan & Periard, 1991
(m) in Parish, 1981
(n) in Pettre & Andre, 1990

Table 1: Air Temperature and Wind Speed Summary at Selected Sites.

2.3 Seasonal Variations

Seasonal variations in wind speed frequency distributions were also computed. A feel for the seasonal variation of wind power potential is provided through the variation of monthly average wind speeds (Figure 2). Later, a better view of the wind power potential seasonal variations will be presented through the output variations of a selected turbine, directly processed from the month-by-month frequency distributions. In general, stronger winds occur during winter, which is promising as stations usually require more power during that period.

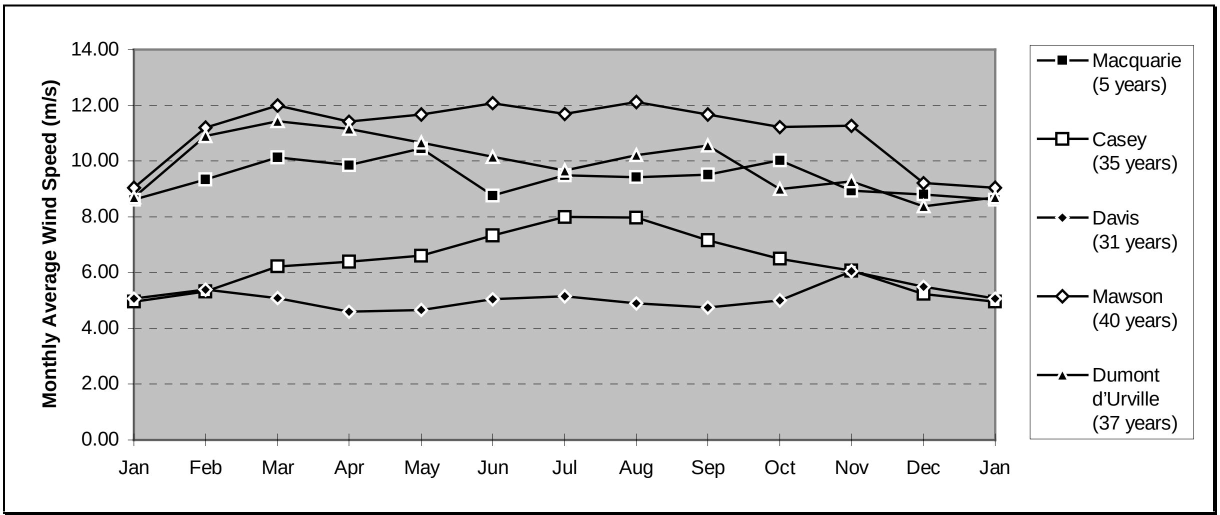

Figure 2: Outline Seasonal Variations of Average Wind Speeds at Selected Locations

2.4 Diurnal Variations

As for the seasonal variations, the average speed variations were examined (Figure 3) in order to get a feel for the wind speed diurnal variations. Mawson shows a significant drop in wind speed during the day while the two Tasmanian sites, Hobart and Maatsuyker Island, show a rise during the day.

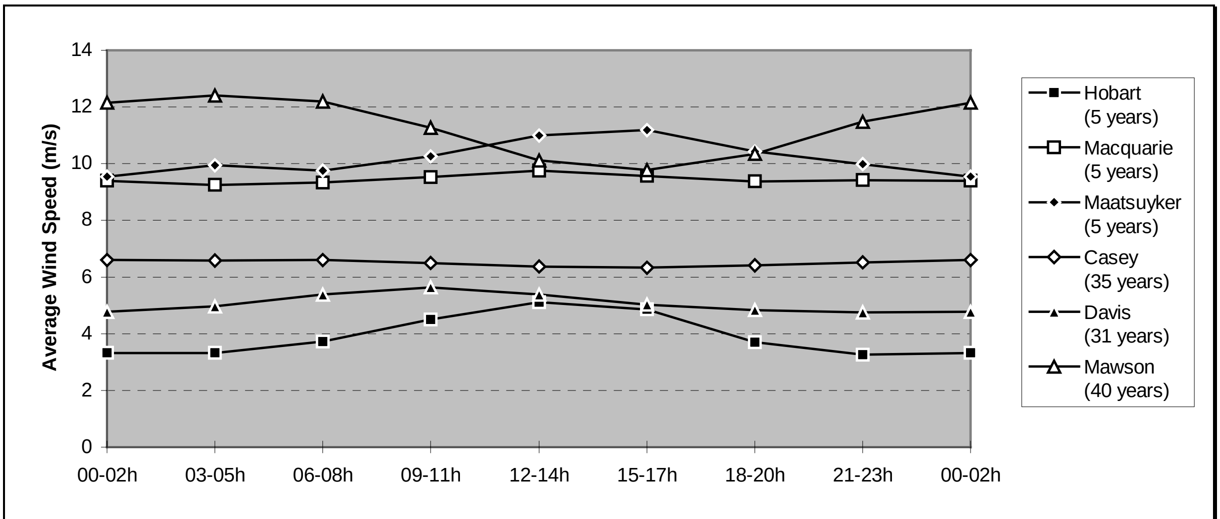

Figure 3: Outline Diurnal Variations of Average Wind Speeds at Selected Locations

3. TURBINE PERFORMANCE

The problems of finding suitable turbines for Antarctic sites have been discussed comprehensively (Guichard & Steel, 1993; Guichard, 1994a & 1994b; Guichard, Magill, Steel & Lyons, 1995).

The potential for wind power generation was recognised during the first expeditions and wind generators were tested and used. The powerful gusty winds combined with low temperatures brought high failure rates. This, as well as energy storage problems and the continuing need for complete back-up systems, led to the withdrawal of wind turbines from Antarctic operations, with the exception of a few small remote field installations for powering limited scientific and communication equipment.

The small turbines which worked in field installations were usually rugged oversized turbines. They are not a realistic option for larger systems designed to power the permanent stations.

Several interesting developments and trials of prototypes have taken place, notably since the mid eighties, but with mixed results.

At Amsterdam Island (37°50S, 77°34E, Sub-Antarctic to Oceanic conditions) in December 1986 an experimental vertical axis 10m diameter Darrieus rotor "CEA30-AD10" (3 blades, 67.7 m2 swept area, rated 30 kW at 13.5 m/s) was installed. It showed early promise with daily energy production of 400 kWh recorded for wind speeds ranging from 12 to 25 m/s (Perroud et al., 1991).

But serious braking problems threatened on several occasions to destroy the machine. These problems were not solved, partly because it wasn't simple and also because the main engineer supporting the project retired. The rotor was locked, then scrapped, the project having lapsed in an atmosphere of general indifference and lack of support.

At Georg Von Neumayer Station (70°37S, 8°22W, Coastal Antarctic) in 1991 a vertical axis 10m diameter H rotor “HMW-56” (3 blades, 56 m2 swept area, rated 20 kW at 9 m/s) was installed. It is characterised by simplicity (permanent magnet, no mechanical transmission), has a survival wind speed of 68 m/s and a minimum operating temperature of -55°C (Heidelberg et al., 1990).

In its second year of operation, it was running continuously without interruptions and breakdowns and producing roughly 5 to 15% of the energy requirement of the station (Kohnen, pers. com., 1993).

Meanwhile, a small number of manufacturers have developed mature commercial products for the limited and specialised market of standalone operation in very difficult wind conditions, cold and/or corrosive environments. These high quality products have already proven their reliability and cost effectiveness in conditions nearly as difficult as the East Antarctic coastal stations and Sub-Antarctic islands where they are now starting to show satisfactory results.

In McMurdo Sound, deep in the Ross Sea, Northern Power Systems “HR3” horizontal axis turbines (3-bladed, 5m diameter, 19.6m2 swept area, 3 kW at 12.5 m/s, DC output, rated survival wind speed of 74 m/s -gusts-) have operated since 1985 in gusts of up to 71 m/s (256 km/h), contributing to a wind-solar-diesel hybrid system powering communication facilities at Black Island near McMurdo Station.

At Heard Island (53°6S, 73°57E, Sub-Antarctic) in 1992/93, a 10kW horizontal axis Aérowatt “UM70X” turbine was used successfully for 3 months, at times producing all of the electrical needs at the five persons Spit Bay station.

This turbine was reerected in early 1995 at Casey Station (66°17S, 110°32E, East Antarctic Coast) and is currently operating successfully. In September, it produced power during 261 hours for a total of 1891 kWh (Scherell, pers. com.), that is an average over the month of 2.63 kW (Load Factor 0.263).

The UM70X is now superseded and surpassed by its new version, the Vergnet “GEV7.10” (2-bladed, variable pitch, 7m diameter, 38.5 m2 swept area, 12 kW at 11.5 m/s, 3-phase 380/415V AC output, rated survival wind speed of 110 m/s -gusts-). A new GEV 7.10 will be installed at the end of 1995 at Casey and monitored in cooperation with Vergnet.

The Vergnet turbines are well designed for extreme wind conditions and, to the best of our knowledge, currently offer the highest resistance to extreme winds in the medium power range together with high efficiency and low maintenance requirements. They have proved their effectiveness in difficult conditions, have survived 90 m/s gusts in the Indian Ocean at Tromelin and have operated satisfactorily since early 1995 at Kerguelen Island (49°21S, 70°14E, Sub-Antarctic).

Although long term reliability has not yet been fully demonstrated at the stations, these two examples tend to indicate that satisfactory operation can be achieved with selected high quality products after proper trials and minor adaptations.

Table 2 lists the characteristics of the two successful horizontal axis commercial turbines HR3 (3kW) and GEV7.10/UM70X(10 kW), the two experimental vertical axis turbines “CEA30-AD10” (Darrieus Rotor, 30 kW) and “HMW-56” (H Rotor, 20 kW), along for comparison with two medium size Australian machines “BW-10” (20 kW) and “S-20000” (3 kW equivalent -no official rating-) as well as the Danish ‘Utility Size’ Vestas “V29” (225 kW).

We have to note that the last three machines are not designed for extreme conditions such as those encountered down south, and that the V29 would not even be suited to the size of the stations and to the associated logistic support. The V29 is definitely not an option for Antarctica but can act as an interesting benchmark.

TURBINE	Rotor Type:	Rotor Diameter (m)	Swept Area (m2)	Hub Height (m)	Nb of blades	Output:	Rated Power (kW)	Max Power (kW)	Min. Operating Temp. (°C)	Survival Wind Gust (m/s)	Priced Configuration	Listed Price	Purchase Price Est. ($A)
GEV 7.10 / UM70X (Vergnet S.A.)	Horizontal Axis, Upwind, Stall Regulated Rotation Speed by Blade Pitch Control	7.0	38.5	18, 24 or 30	2	AC, 3 phase grid compatible, Asynchronous Generator 220-240V, 380-415V, 50Hz	10	12.44	?	90	turbine, 24m tower	211 000 (FRF)	57 000
HR3 (Northern Power Systems)	Horizontal Axis, Upwind, Fixed Pitch, Variable Axis Control, Direct Drive	5.0	19.6	12 to 30	3	DC, 24, 48 or 110V, 3 phase synchronous generator	3	3.10	-60	74	turbine, tower & controller	17 000 (USD)	22 000
BW-10-Standard (Bergey/Westwind)	Horizontal Axis, Upwind, Auto Tail Furl, Direct Drive	7.0	38.5	12 or 18	3	DC, 96 or 120V, Permanent Magnet Generator	10	9.95	-40	60	turbine, 18m tower, controller, extra stiff blade option		34 250
Survivor S-20000 (Synergy Power Corporation)	Horizontal Axis, Downwind Variable Rotor Area, Gearbox 2.78:1	5.8	26.4		3	DC, 24 or 48 V Permanent Magnet Generator	3	3.00	?	?	turbine, 25m tower, Control Panel		22 863
HMW 56 (Heidelberg Motor et al.)	Vertical Axis, H-Rotor Direct Drive	10.0	56.0	10.0	3	AC, Variable Frequency Permanent Magnet Travelling Field generator	20	?	-55	68	n/a	n/a	n/a
CEA-30 AD10 Variable Speed (CEA-Grenoble)	Vertical Axis, Darrieus Rotor, Gearbox	10.0	67.0	15.0	3	AC, 3 phase Variable Frequency Synchronous Generator	30	29.10	?	?	n/a	n/a	n/a
Vestas V29 (Vestas Wind Systems A/S)	Horizontal Axis, Pitch Regulated, Gearbox 24.6:1	29.0	661.0	31.5	3	AC, 3 phase Grid Compatible Asynchronous Generator 420V, 50Hz	225	225	?	?			

Table 2 : Main Characteristics of Selected Wind Turbines

For each of these turbines, from the information available, an outline power curve was constructed destined to match the wind speed frequency distributions, that is, for each bin, a single averaged 'Instant Power Output' value was computed. This provides a qualitative measure of the various turbines' potential output and suitability to various wind conditions.

Figure 4 shows the shape of the power curves (normalised curves: power output divided by the maximum output). The tail part of these curves can in some cases be quite approximate, especially for the S-20000 turbine for which no data point exists above 10 m/s but for which the manufacturer expects a full output until 20 m/s, then a drop (maybe of 10%) until 50 m/s. We have conservatively cut the curve above 37 m/s, which will only introduce a small error as the frequency of such wind speeds is negligible (see Fig. 1).

The following points should be noted: the relatively large curve envelopes of the V29, S20000 and GEV7.10/UM70X which could generate large amounts of power in windy areas, and the very early start of the S20000 which allows good production in areas of moderate winds.

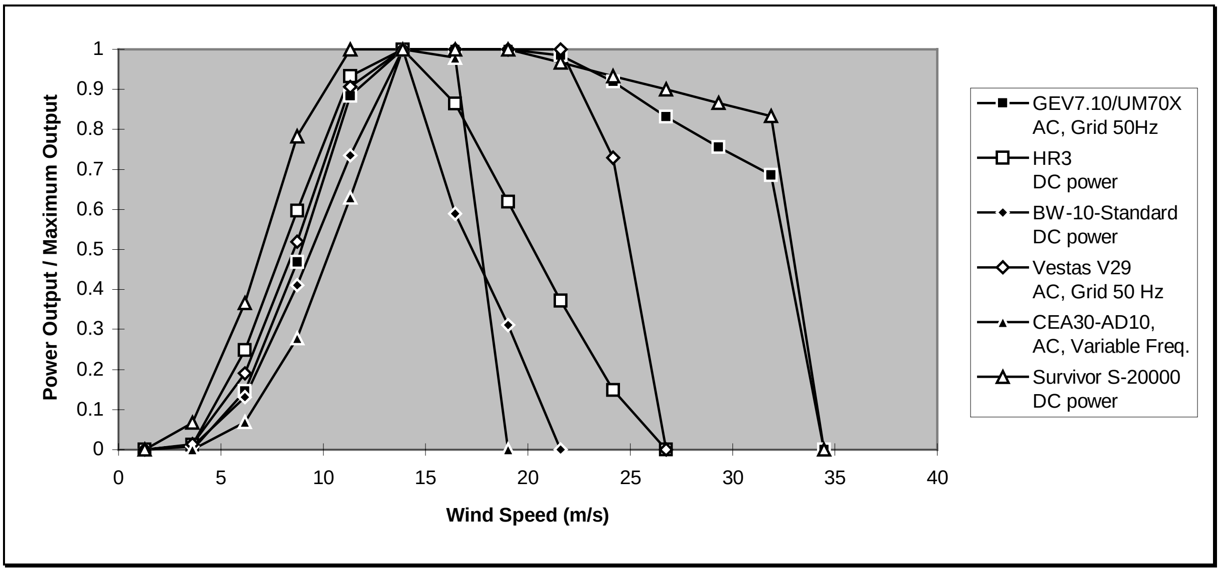

Fig. 4: Normalised Power Curves of Selected Wind Turbines

4. WIND POWER POTENTIAL

For a preliminary assessment of the power output achievable at the stations, the power curves have been applied to the wind speed (at 10m height) frequency distributions obtained earlier. No corrections for air density or hub height were applied.

In studying the results it should be remembered that some of the turbines were only included for comparison purposes and wouldn't currently be expected to behave properly in extreme environments for which they were never intended. This is especially true for the Vestas V29 which is not an option but was included to provide a benchmark of mature large scale wind generation solutions.

4.1 Average Output

The estimation of the average output (and average load factor) of turbines at the stations is only a first step towards the assessment of complete production systems, but is a good way to overview the potential for wind generation, notably as a simple additional contributor to the existing systems.

For easier comparisons, Figure 5 shows the average load factor (power output / power rating) rather than the average power output of the turbines. The load factor will be interesting both to determine the number of turbines needed which is also constraint by problems of space availability and environmental aspects, and to evaluate production costs.

The plots show on an "efficiency basis" the superiority of the GEV7.10/UM70X and the S20000, with an advantage (expected) to the S20000 in the low winds sites and a slight advantage to the GEV7.10/UM70X in high winds sites, reinforced by its known survivability.

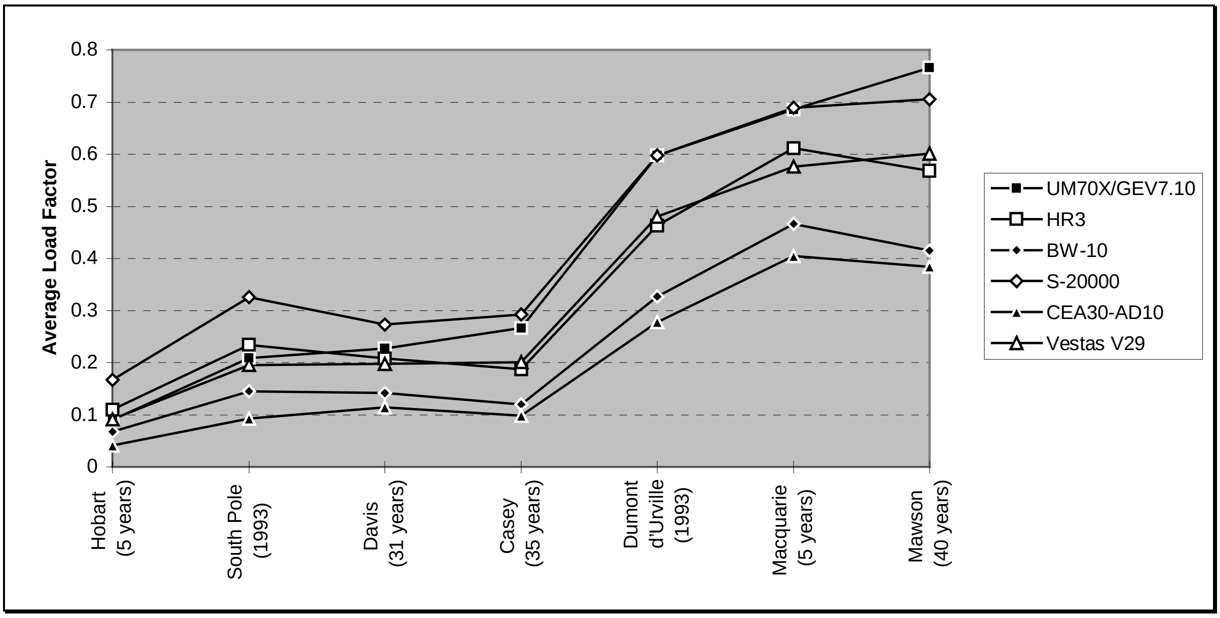

Figure 5: Average Load Factors for Selected Turbines and Locations

4.2 Relative Cost Indications

The Relative Cost Indicator plotted on Figure 6 and listed in Table 3 was calculated directly from the above average load factors and the turbine prices quoted on Table 2 by spreading the initial capital cost over the number of kWh ideally produced over a 20 year life cycle, assuming the absence of breakdowns. It does not take into account the difference between turbines regarding breakdown times and maintenance/repair costs. This indicator should then only be taken as a limited and relative cost indicator.

Turbine purchase prices quoted correspond to the configuration required to produce the output listed in Table 2. It should be noted that the production costs don't all correspond to the same form of electrical power, and that therefore, the supply of a specific form of power required could incur different transformation costs depending on the turbine used.

The results show high cost indicators for the HR3, but the HR3 reliability has been fully demonstrated. The GEV7.10/UM70X obtains the lowest cost indicator at Casey, Dumont d'Urville and Mawson where it is expected to show good reliability. The BW-10 shows the lowest indicator at Davis, where the relatively mild wind conditions could allow the rotor to survive. The lowest indicator at Macquarie Island corresponds again to the BW-10 but it would be fairly unlikely to see the rotor survive on the island, where the cheapest option would then likely be the reliable GEV7.10/UM70X with a cost indicator just slightly higher. The S20000 would be the cheapest at Hobart, as well as at South Pole providing that it would function properly in temperatures as low as -82.8°C! Consideration would need to be given to the integrity of the BW10's and S20000's permanent magnet generators in the cold Antarctic winters, and even in summer at South Pole.

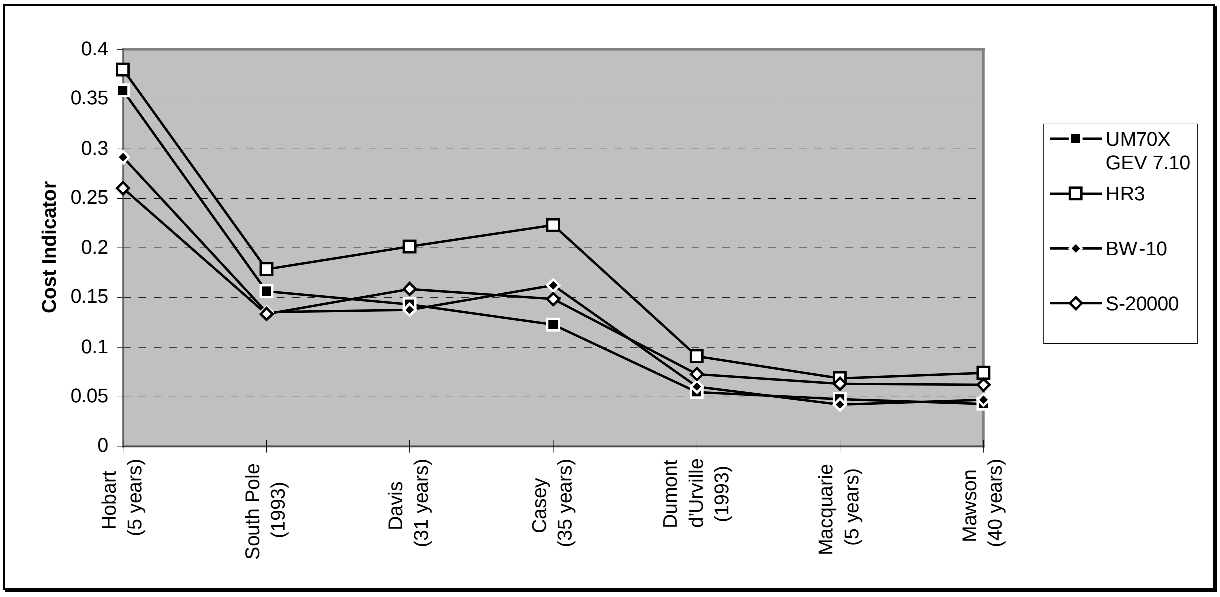

Figure 6: Relative Cost Indicator of Selected Turbines at Various Sites
(20 years life cycle, no maintenance/repair/breakdown taken into account)

Location (Extent of Met Data Used)	**GEV 7.10 / UM70X**	**HR3**	**BW-10**	**S-20000**
Hobart .... (5 years)	0.359	0.380	0.291	0.260
South Pole .... (1 year)	0.156	0.178	0.135	0.134
Davis .... (31 years)	0.143	0.201	0.138	0.159
Casey .... (35 years)	0.122	0.223	0.162	0.149
Dumont d'Urville ... (1 year)	0.054	0.090	0.060	0.073
Macquarie .... (5 years)	0.047	0.068	0.042	0.063
Mawson .... (40 years)	0.042	0.074	0.047	0.062

Table 3: Relative Cost Indicator of Selected Turbines at Various Sites
(20 years life cycle, no maintenance/repair/breakdown taken into account)

4.3 Seasonal Variations

The month-by-month frequency distributions were processed with the power curve of the GEV7.10/UM70X to view seasonal variations in the power output. The results are plotted on Figure 7. It is interesting to note that there tends to be more wind power available during winter, while the stations typically require much more power during the long cold and dark winter due to higher heating and lighting needs, as illustrated on Figure 8 by the 1992 Energy production at Davis. A good seasonal match between power needs and wind power availability would contribute to the viability of comprehensive renewable systems by allowing reasonably sized storage installations. In this regard, Mawson and Casey potential patterns are clearly promising. Dumont d'Urville and South Pole potential seem promising but will need to be clarified by the use of extended data sets, as the results presented here are only based on 1 year of data.

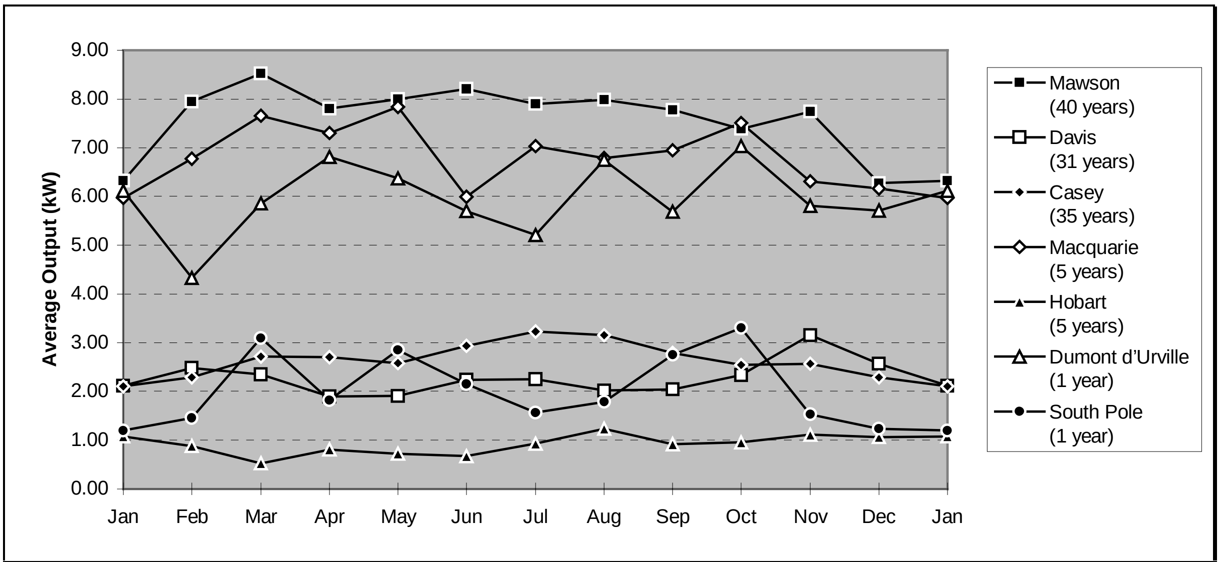

Figure 7: Seasonal Variation of GEV7.10/UM70X Power Output for Selected Locations

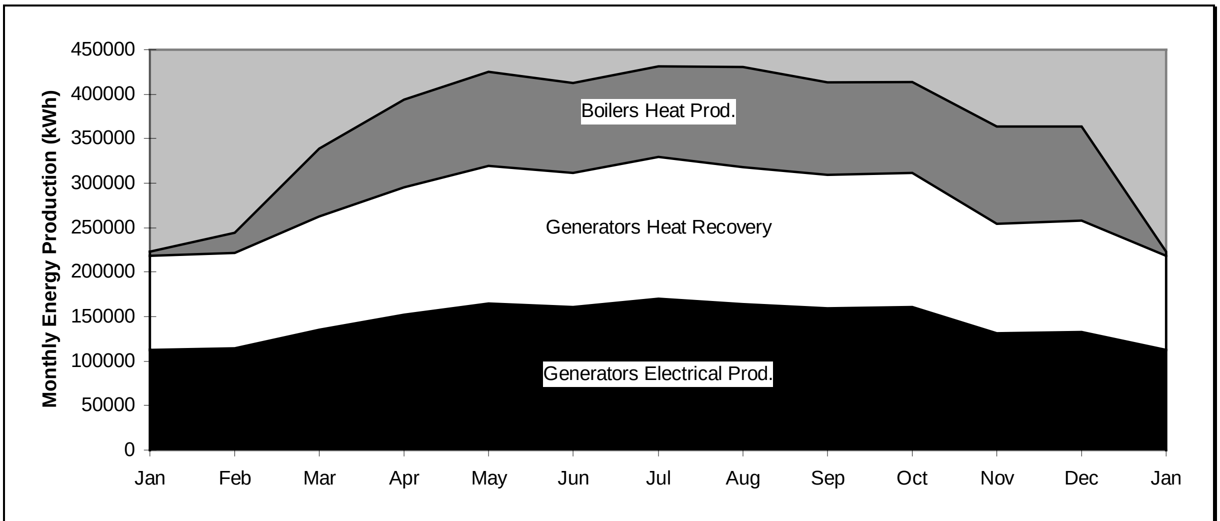

Figure 8: Seasonal Variations of Energy Production at Davis in 1992

4.4 Diurnal Variations

The 3 hour by 3 hour frequency distributions were processed with the power curve of the GEV7.10/UM70X to view power output diurnal variations. The results are plotted on Figure 9. The most significant trend is for Mawson and Mirny, with a clear power drop during daytime. Dumont d'Urville, the third site exposed to Katabatic winds, shows a similar but weaker trend. Casey shows a fairly flat curve while Davis has a maximum in the mornings, South Pole a maximum in the late afternoon. Both Macquarie and Hobart tend to have increased power over daytime.

Although further work should be done on the matching of power needs and diurnal wind variations, the relatively short time frame over which the variations occur has much less influence on energy storage system optimisation than the longer term seasonal variations.

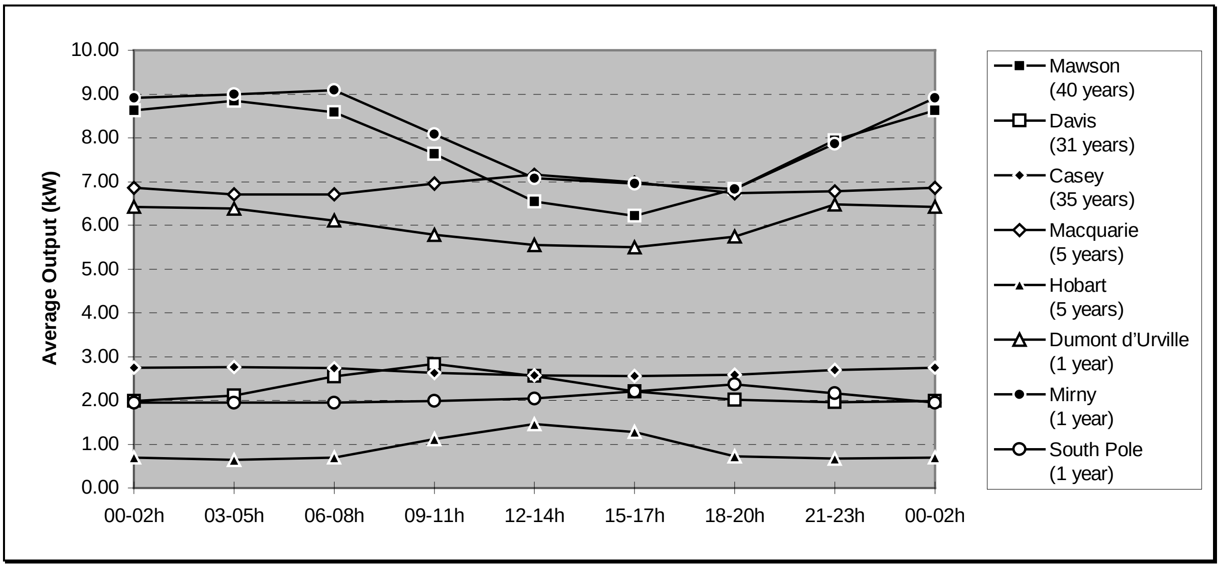

Figure 9: Diurnal Variation of GEV7.10/UM70X Power Output for Selected Locations

5. CONCLUSIONS

There is considerable potential for the application of wind power at Antarctic station sites, particularly given the need for environmentally sound, locally produced power. But experience shows that very few turbines will survive the severe conditions.

The high failure rates of the past have not only led to the withdrawal of turbines from the stations but have seriously discredited wind power and its ability to serve Antarctic stations.

Recent and ongoing trials of selected machines have showed good promise. Further trials and progressive installation of wind generators, connected to the existing grid or powering specific buildings or applications, will allow a move towards more energy sustainability at the Antarctic stations.

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