

WIND POWER DEVELOPMENT IN SUB-ARCTIC CONDITIONS WITH SEVERE RIME ICING



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John F. Maissan, P.Eng.,
Director, Technical Services
Yukon Energy Corporation

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John F. Maissan, P. Eng., Director, Technical Services
Yukon Energy Corporation
P. O. Box 5920
Whitehorse, Yukon
Y1A 5L6
Canada
Telephone (867) 393-5347
Fax (867) 393-5322

INTRODUCTION

Yukon is the North-Westerly most part of Canada and lies immediately East of Alaska. It has a population of about 33,000 people, two thirds of which live in the capital city, Whitehorse, situated in South central Yukon.

Electrical energy is supplied principally from two hydro-electric plants located on the main (Southern) power grid and a third on a small grid in central Yukon. However, peaking energy and capacity are normally supplied by diesel generators. As well, there are 8 communities that are supplied by entirely by diesel plants because they are not connected to either of these hydro based power grids.

With the mining industry in full operation, electrical loads can peak at up to 78 MW in the main grid in the coldest days of winter. Annual energy requirement with this mining load on is about 450 GWh. At present the mining load is shut down, resulting in peak loads of just over 50 MW and annual energy requirements of only 250 GWh (there is now a hydro-electric energy surplus). In the diesel served communities the annual energy requirement totals about 50 GWh.

The climate in Whitehorse is sub-arctic, mean daily January lows are -25°C with the lowest temperatures around -40°C , and occasionally to -45°C or lower. Weather data analyses have shown that at altitudes of 4,000 to 6,000 feet rime icing can occur from 800 to 1200 hours per year -- equivalent to a continuous duration of 4 to 7 weeks per year. Rime icing is the buildup of ice on anything solid from moist, supersaturated air at sub-zero temperatures. Essentially whenever and wherever there is a cloud on a mountain there is rime icing (cover photograph). Rime ice looks like the pretty frost that builds up on trees around open water in the winter. In our location rime icing is most severe in the early winter: mid October to the end of December. Severe rime ice on wind monitoring equipment is illustrated in Photograph 1.

BACKGROUND

The potential for commercial wind power generation in Yukon was investigated in the early and late 1980s on the basis of data from airports and two wind monitoring stations. In all cases the conclusion was that it was not economic.

In 1990 two local citizens investigated Environment Canada's upper air data and found that wind speeds increased substantially with altitude. This led to the establishment of a 65 foot (20 meter) wind monitoring station on a shoulder of Mt. Sumanik that is known locally as Haeckel Hill, located west of the city. This site has an altitude of about 4,700 feet (1430 meters), about 2500 feet above the valley floor, and consists of a ridge perpendicular to the prevailing wind. Road access and a single phase power line to a forest fire look out tower located on top were positive factors in the selection of this site. Monitoring results confirmed the higher wind speeds at higher altitudes, but also found severe rime icing conditions at the site. Another interesting feature, since confirmed by long term monitoring, is that inversions keep the temperatures from reaching the low extremes, it seldom drops below -30°C (-22°F) even with valley temperatures down to -45°C (-50°F) or lower.

A subsequent analysis of upper air data (Table 1) showed that the annual average wind speed at 4,000 feet was 6.6 m/s (meters per second), at 5,000 feet was 6.9 m/s, and at 6,000 feet was 7.3 m/s. Since the kinetic energy in wind increases with the cube of the wind speed, these are significantly better than the 3.9 m/s long term average at the airport. It is also very significant that the wind speeds are much higher in winter than in summer, almost perfectly following the seasonal electrical load profile. It was felt that with these wind speeds commercial wind power could be cheaper than diesel generation if the low temperatures and the effects of the rime icing could be overcome. Producing electrical power at costs below the cost of diesel generation was and remains our primary goal. Environmental benefits are the icing on the cake.

THE FIRST WIND TURBINE

Since the monitoring generally confirmed the upper air wind regime, and found that severe rime icing was present there, it was decided, in 1992, that a program of adaptation of commercial wind generating equipment to this climate was needed. With our limited resources we decided that we could not do anything other than take existing, proven commercial equipment and try to adapt this to our conditions. Several large, reputable manufacturers were considered and Bonus Energy A/S of Denmark was selected for their 150 kW MARK III unit. This 150 kW machine, a conventional three bladed, horizontal axis, up wind and stall regulated design, represented the small end of the commercial range available and therefore the lowest capital cost. Bonus was a large proven commercial equipment supplier with a good reputation, had some northern experience, was willing to work with Yukon Energy on modifications, and had a hinged tower design for a winch up raising that did not require a large crane to be brought in from southern Canada.

In consultation with Bonus a number of modifications were made to their standard design. A hinged, winch up 30 meter tower was an important feature. To overcome the effects of the cold, low temperature tolerant steels were selected for the tower plus

other key components, and synthetic lubricants (including hydraulic fluid) were used throughout. Electric heaters, controlled by thermostats, were installed on the gearbox, in the generator, in the computer control cabinet, and in the radio communications cabinet.

To overcome rime icing effects the anemometer and wind vane used to control the turbine were equipped with heated bearings. The blades were equipped with heating strips about 6 inches wide and running along the entire length of the leading edge. The heat output was about 1/4 watt per square inch, or 1,700 watts for all three blades. An ice detector to turn the blade heating on and off was also supplied. The power production target was set at 300,000 kWh per year representing a capacity factor of 22.8% (Table 1).

A firm order for this unit, plus a two year service agreement from the manufacturer, was placed in December 1992. The turbine was erected in July of 1993 (Photograph 2) and was commissioned on August 13. The project cost about \$CDN 800,000, of which \$CDN 200,000 was for upgrading the road and power line. Yukon Energy received a grant of \$300,000 from government sources toward the project.

PROJECT RESULTS

Rime icing causes were briefly described in the introduction. The practical effects can be substantial. Any solid object accumulates ice which “grows” into the wind (Photograph 3). Trees become ice domes, towers become ice posts, power lines grow to six or eight inches in diameter, and chain link fences become solid walls. As you can see it is no wonder that exposed equipment has difficulty working under these conditions. Low temperatures and severe rime icing are the challenges we need to overcome.

The following features have worked well and have not needed further attention:

1. The winch up tower worked well even though it is not as easy to winch up or down as expected.
2. The low temperature steels have not been a problem so far.
3. Lubrication with synthetic products has worked well.
4. The heating systems in the gearbox, generator, and electronic cabinets have been very reliable.

Aspects of the project that did not work initially but have since been overcome are:

1. The heated bearing anemometer and wind vane were still immobilized by ice and were replaced with fully heated Hydro-Tech instruments which have not iced up (Photograph 1).
2. The overhead power line was causing about five outages per month due to the heavy accumulation of ice in combination with wind, and was replaced with a buried cable which is not affected by the ice.

3. The Ice detector supplied with the turbine was not effective and was removed from the control circuit. The heating circuits are now simply switched on for the winter. A Rosemount ice detector was purchased in 1996 and has been running reliably on site since then, but has not been installed into the turbine control circuit. This ice detector has indicated that we average over 800 hours of rime icing per year on the site.

One aspect of the project that did not work and has not been overcome is the inability of the electrical contacts between the main portion of the blades and the tips to work reliably under icing conditions. Several redesigns have also failed to operate reliably.

The leading edge blade heaters (1/4 watt per square inch) have worked reasonably well even though one burnt out in 1996. We replaced them all in 1998 with heaters 12 inches wide, rather than 6 inches, to improve performance in very severe rime icing and in very cold temperature conditions. Perhaps because of other problems and advances we have not been able to attribute specific production improvements to the larger heaters.

The effect of rime icing on the blades of the wind turbine is such an important issue that it is worth examining in detail. Without blade heaters rime ice builds up especially heavily on the leading edges, and the build up increases with distance from the blade root (Photograph 4). It seems to be directly related to the velocity at any point and therefore perhaps the amount of moisture or moist ice contacted. When shut down the ice builds up on the edges of the blade surface facing the wind, the pressure side. When running through an icing event the ice build up on the "back", or suction side, of the blade is much less than on the "front" (Photograph 5). Ice can also build up on the trailing edge. Power production drops off dramatically when the blades are coated with rime ice and without leading edge blade heaters can stop altogether (Graph 1).

The 6 inch wide heaters did, under lighter icing conditions, keep portions of the blade downwind of the heater clear (Photograph 6). Under heavier icing conditions ice would build up on the blade right up to the heater (Photograph 7). Build up of ice on the leading edges did not occur except under the most severe conditions, and it cleared off quite quickly afterwards. It was from this that we concluded that more heat on the front of the blade in the form of wider leading edge heaters would be of benefit if the increased area was applied to the front (pressure side) of the blade. It was also obvious that the leading edges of the blade tip would need to be heated to minimize the air drag and associated production losses.

One aspect of the project that was very positive was the bird monitoring work. Concern over the possibility of bird kills in collision with the turbine blades, especially during spring and fall migrations, led to a five year monitoring program. It was found that the migrating waterfowl, at least, stayed lower down in the valley well below the altitude of the turbine. The only bird mortality documented in the program was a grouse that flew into the chain link fence.

POWER PRODUCTION

From a production perspective the project has not yet met the target but, all considered, we are satisfied with our accomplishments. In the first year we solved the power line and control instrument problems. Once those were resolved performance improved substantially.

In the third year of operation we had a failure of one of the blade heaters early in winter and we had to operate without any leading edge heat for the rest of the winter. With the heaters working on only two of the blades there was a significant blade weight imbalance. At this time annual "losses" due to rime icing were estimated to be in the range of 60,000 to 70,000 kWh per year, about 20% of the production target.

Repairs to the power line (a local feeder) were made in 1996 and since that time there have been very few of the electronic problems that bothered us early on, and turbine availability has been very high. Also in 1996 we "painted" the blades with a black coloured coating called StaClean. We believed that the solar heating from the black colour would assist in clearing the blades of accumulated rime ice, and we felt that the special low adhesion formula for ice could be beneficial too. We saw an immediate noticeable improvement in performance, 1998 and 1999 have been the best production years yet. Photograph 8 shows accumulated ice shedding from the blades.

On the whole we are pleased with the performance, especially considering where the turbine is physically located, the unfamiliarity of maintenance personnel with this type of equipment, and our dependence on a few key people. Due to the ladder being outside for the top portion of the tower and the weather exposed servicing, maintenance is not done during severe weather conditions. Detailed monthly performance statistics from project commissioning are presented in Table 2. Annual figures based on revenue metering which commenced in July 1994 is presented in Table 3.

THE SECOND WIND TURBINE

With funding from the Yukon government, the Yukon Energy installed a new larger wind turbine this past September, a Vestas 660 kW V47 LT II, low temperature version (photograph 9). This turbine incorporates most of the features that we believe will move wind energy from the development phase into commercial viability. This machine is a pitch regulated machine designed for unrestricted operation down to -30° C (-22° F). It was fitted with fully heated wind instruments, StaClean coated (black) blades and leading edge blade heaters. Our experience with the stall regulated 150 kW machine have convinced us that a pitch regulated machine will lose less power when affected by rime ice as the lowering of the stall wind speed is not as critical with the pitch regulation design. In the higher wind speeds the blades will remain pitched to a more aggressive angle until full output is achieved. Since the blades do not have tip brakes maintaining electrical continuity and effective heating to the very tip should not be a problem.

Two features that we would have liked to have had but were not able to get in a turbine in the 500 to 1,000 kW size range this time, were a full surface blade heating system, and an operating temperature range down to -40°.

The new turbine was installation was completed in mid September (photograph 10). Detailed performance comparisons between the two turbines has not been possible so far. We are still in the process of fine tuning the various operating and control systems. These analyses will be part of our work in the coming years.

SUGGESTIONS FOR SIMILAR APPLICATIONS

For anyone contemplating a wind turbine in a cold, severe rime icing environment such as Haeckel Hill, which is on the warmer side of typical of the interior of Yukon and Alaska, we would recommend the following:

1. Low temperature steels
2. Low temperature synthetic lubricants and fluids
3. Equipment heaters (gearbox, generator, control cabinets)
4. Fully heated wind instruments
5. Black coloured fluorourethane (StaClean) coated blades
6. Full surface blade heating if available, or otherwise leading edge heaters at least 12 inches wide
7. For simplicity and reliability in leading edge heating one piece blades would be better than the two piece such as we have on our Bonus machine
8. Tubular tower for "indoor" climbing and maintenance work for shelter from the weather
9. Pitch or active stall regulation as we believe this will result in higher power production

CONCLUSION

In conclusion, substantial progress has been made in understanding the effects of rime icing on wind turbines and in learning how to overcome them. It is our goal to establish a track record of performance under these conditions that puts wind power into the list of realistic and practical power supply options available to us in Yukon. Like the trees that survive in these conditions we northerners need to stand together, we need to be tough, we need to be innovative, we need to be persistent, and, most importantly, we need a strong positive attitude.

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**TABLE 1
WHITEHORSE UPPER AIR WIND SPEEDS AND BONUS PRODUCTION TARGETS**

| Whitehorse, Yukon Mean Wind Speeds 1980 - 1995 | | | | | Bonus 150 Production Targets | |
|---|------------------------|------------|------------|------------|---------------------------------|---------------------------|
| Month | (Airport) 2305' ASL | 4000' ASL | 5000' ASL | 6000' ASL | Target kWh | Target Capacity Factor |
| January | 3.6 | 8.5 | 8.7 | 9.2 | 30.000 | 26.9% |
| February | 4.1 | 7.9 | 8.3 | 9.0 | 28.000 | 27.8% |
| March | 4.0 | 6.9 | 7.3 | 7.7 | 28.000 | 25.1% |
| April | 4.0 | 6.2 | 6.5 | 6.8 | 25.000 | 23.1% |
| May | 4.0 | 5.6 | 5.8 | 6.1 | 24.000 | 21.5% |
| June | 3.6 | 5.0 | 5.0 | 5.3 | 15.000 | 13.9% |
| July | 3.4 | 4.3 | 4.6 | 4.8 | 15.000 | 13.4% |
| August | 3.3 | 5.5 | 5.5 | 5.8 | 18.000 | 16.1% |
| September | 3.4 | 6.6 | 6.9 | 7.6 | 27.000 | 25.0% |
| October | 4.6 | 7.7 | 8.1 | 8.5 | 30.000 | 26.9% |
| November | 4.4 | 7.9 | 8.3 | 8.4 | 30.000 | 27.8% |
| December | 4.0 | 8.2 | 8.5 | 9.0 | 30.000 | 26.9% |
| Annual | 3.9 | 6.6 | 6.9 | 7.3 | 300.000 | 22.8% |

Graph 1 Rime Icing Effects on Power Production Curves

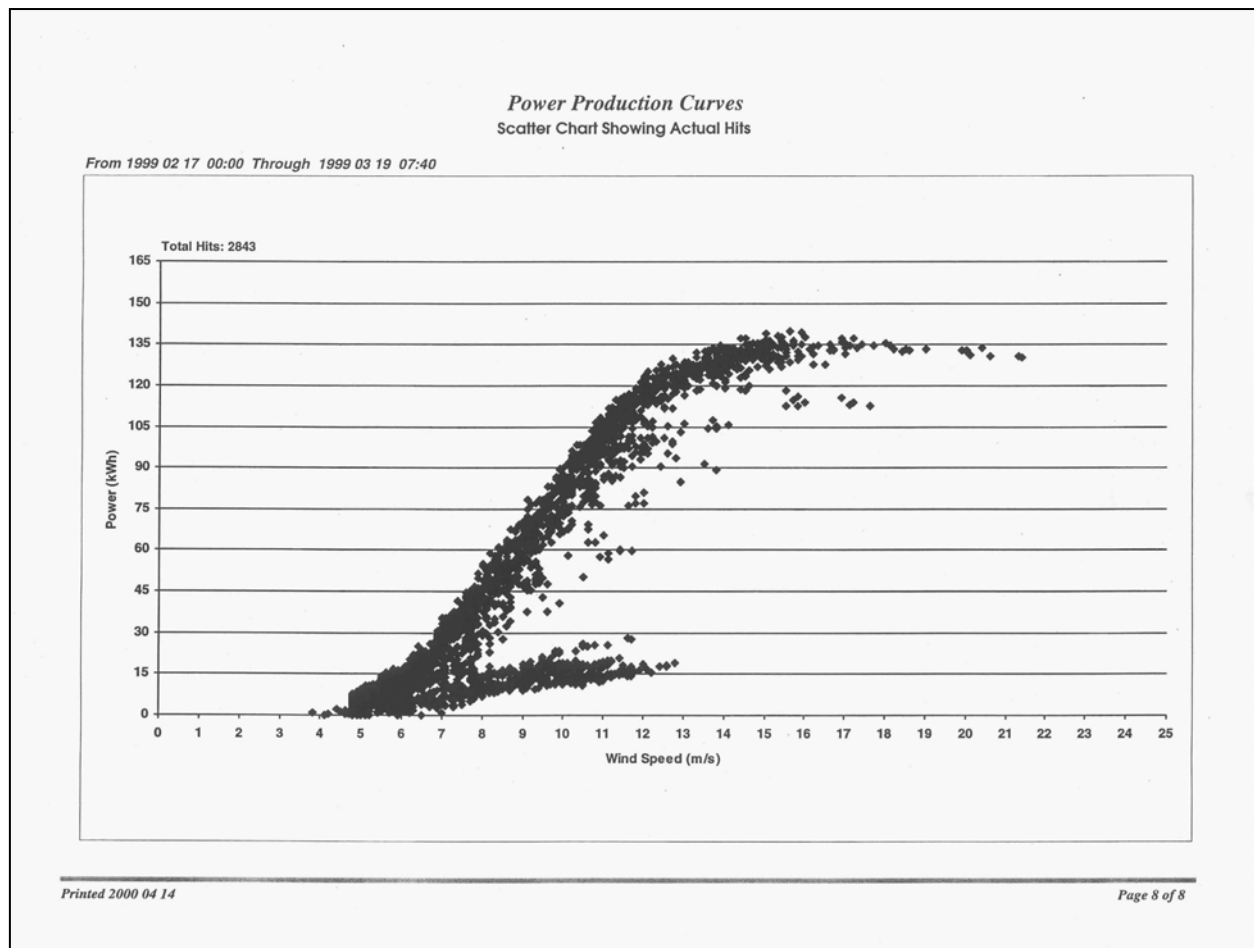


Table 2 Detailed Production Record

| WIND TURBINE PRODUCTION DATA | | | | | | | | | | | |
|-------------------------------------|--------------------|--------------------|-----------------------|---------------------|-------------------------|--------------------------|--------------------|-----------------------|-----------------------|----------------------------|--------------------|
| Month | Prod. (kWh) | Total Hours | Hours in Prod. | Maint. Hours | Break Down Hours | Grid Outage Hours | Cap. Factor | Turbine Avail. | Overall Avail. | Revenue Meter Gross | Cap. Factor |
| Aug-93 | 10,949 | 408 | 222 | 0 | 0 | 0 | 17.9% | 100.0% | 100.0% | | |
| Sep-93 | 19,290 | 720 | 379 | 7 | 19 | 58 | 17.9% | 96.4% | 88.3% | | |
| Oct-93 | 15,890 | 744 | 309 | 12 | 48 | 24 | 14.2% | 91.9% | 88.7% | | |
| Nov-93 | 21,331 | 720 | 331 | 14 | 1 | 163 | 19.8% | 97.9% | 75.3% | | |
| Dec-93 | 18,728 | 744 | 317 | 36 | 3 | 186 | 16.8% | 94.8% | 69.8% | | |
| Tot-93 | 86,188 | 3,336 | 1,558 | 69 | 71 | 431 | 17.2% | 95.8% | 82.9% | | |
| Jan-94 | 4,896 | 744 | 152 | 40 | 96 | 300 | 4.4% | 81.7% | 41.4% | | |
| Feb-94 | 11,335 | 672 | 320 | 37 | 0 | 0 | 11.2% | 94.5% | 94.5% | | |
| Mar-94 | 38,262 | 744 | 652 | 4 | 9 | 0 | 34.3% | 98.3% | 98.3% | | |
| Apr-94 | 26,666 | 720 | 570 | 12 | 0 | 0 | 24.7% | 98.3% | 98.3% | | |
| May-94 | 24,227 | 744 | 505 | 0 | 26 | 0 | 21.7% | 96.6% | 96.6% | | |
| Jun-94 | 14,849 | 720 | 225 | 0 | 0 | 6 | 13.7% | 100.0% | 99.2% | | |
| Jul-94 | 15,307 | 744 | 400 | 0 | 0 | 3 | 13.7% | 100.0% | 99.6% | 17320 | 15.5% |
| Aug-94 | 10,980 | 744 | 385 | 5 | 61 | 26 | 9.8% | 91.2% | 87.7% | 12090 | 10.8% |
| Sep-94 | 28,636 | 720 | 542 | 0 | 17 | 0 | 26.5% | 97.6% | 97.6% | 29230 | 27.1% |
| Oct-94 | 28,326 | 744 | 549 | 37 | 0 | 0 | 25.4% | 95.0% | 95.0% | 30980 | 27.8% |
| Nov-94 | 19,415 | 720 | 422 | 0 | 67 | 0 | 18.0% | 90.7% | 90.7% | 22430 | 20.8% |
| Dec-94 | 20,541 | 744 | 442 | 0 | 0 | 0 | 18.4% | 100.0% | 100.0% | 22144 | 19.8% |
| Tot-94 | 243,440 | 8,760 | 5,164 | 135 | 276 | 335 | 18.5% | 95.3% | 91.5% | | |
| Jan-95 | 21,363 | 744 | 511 | 0 | 0 | 12 | 19.1% | 100.0% | 98.4% | 23760 | 21.3% |
| Feb-95 | 27,379 | 672 | 423 | 0 | 0 | 0 | 27.2% | 100.0% | 100.0% | 29620 | 29.4% |
| Mar-95 | 18,060 | 744 | 344 | 0 | 288 | 0 | 16.2% | 61.3% | 61.3% | 18790 | 16.8% |
| Apr-95 | 24,299 | 720 | 559 | 0 | 0 | 0 | 22.5% | 100.0% | 100.0% | 27190 | 25.2% |
| May-95 | 20,395 | 744 | 478 | 12 | 0 | 7 | 18.3% | 98.4% | 97.4% | 22210 | 19.9% |
| Jun-95 | 12,751 | 720 | 339 | 0 | 99 | 2 | 11.8% | 86.3% | 86.1% | 14380 | 13.3% |
| Jul-95 | 8,298 | 744 | 306 | 0 | 49 | 3 | 7.4% | 93.4% | 93.1% | 9230 | 8.3% |
| Aug-95 | 14,785 | 744 | 306 | 0 | 0 | 0 | 13.2% | 100.0% | 100.0% | 16080 | 14.4% |
| Sep-95 | 31,919 | 720 | 571 | 8 | 0 | 0 | 29.6% | 98.9% | 98.9% | 34030 | 31.5% |
| Oct-95 | 13,911 | 744 | 368 | 6 | 0 | 1 | 12.5% | 99.2% | 99.0% | 15742 | 14.1% |
| Nov-95 | 11,265 | 720 | 313 | 9 | 0 | 2 | 10.4% | 98.8% | 98.6% | 11991 | 11.1% |
| Dec-95 | 22,736 | 744 | 477 | 3 | 11 | 9 | 20.4% | 98.2% | 97.0% | 25226 | 22.6% |
| Tot-95 | 227,161 | 8,760 | 4,995 | 37 | 447 | 35 | 17.3% | 94.5% | 94.1% | 248249 | 18.9% |
| Jan-96 | 971 | 744 | 42 | 0 | 702 | 0 | 0.9% | 5.6% | 5.6% | 1020 | 0.9% |
| Feb-96 | 26,597 | 696 | 470 | 16 | 0 | 2 | 25.5% | 97.7% | 97.5% | 29257 | 28.0% |
| Mar-96 | 38,309 | 744 | 559 | 0 | 0 | 0 | 34.3% | 100.0% | 100.0% | 41599 | 37.3% |
| Apr-96 | 12,060 | 720 | 226 | 3 | 114 | 273 | 11.2% | 83.8% | 45.8% | 14408 | 13.3% |
| May-96 | 16,275 | 744 | 412 | 6 | 81 | 0 | 14.6% | 88.4% | 88.4% | 18009 | 16.1% |
| Jun-96 | 17,488 | 720 | 496 | 0 | 0 | 2 | 16.2% | 100.0% | 99.7% | 19130 | 17.7% |
| Jul-96 | 6,216 | 744 | 259 | 192 | 7 | 0 | 5.6% | 73.3% | 73.3% | 7317 | 6.6% |
| Aug-96 | 11,037 | 744 | 391 | 205 | 0 | 0 | 9.9% | 72.4% | 72.4% | 11803 | 10.6% |
| Sep-96 | 24,850 | 720 | 494 | 6 | 0 | 10 | 23.0% | 99.2% | 97.8% | 27490 | 25.5% |
| Oct-96 | 14,376 | 744 | 377 | 43 | 0 | 0 | 12.9% | 94.2% | 94.2% | 13502 | 12.1% |
| Nov-96 | 24,890 | 720 | 475 | 0 | 0 | 0 | 23.0% | 100.0% | 100.0% | 27716 | 25.7% |
| Dec-96 | 27,601 | 744 | 441 | 6 | 0 | 0 | 24.7% | 99.2% | 99.2% | 31604 | 28.3% |
| Tot-96 | 220,670 | 8,784 | 4,642 | 476 | 904 | 287 | 16.7% | 84.3% | 81.0% | 242,855 | 18.4% |

| Month | Prod. (kWh) | Total Hours | Hours in Prod. | Maint. Hours | Break Down Hours | Grid Outage Hours | Cap. Factor | Turbine Avail. | Overall Avail. | Revenue Meter Gross | Cap. Factor |
|---------------|------------------|---------------|----------------|--------------|------------------|-------------------|--------------|----------------|----------------|---------------------|--------------|
| Jan-98 | 14,600 | 744 | n/a | 0 | 0 | n/a | 13.1% | 100.0% | n/a | 15698 | 14.1% |
| Feb-98 | 31080 | 672 | n/a | 0 | 0 | n/a | 30.8% | 100.0% | n/a | 32048 | 31.8% |
| Mar-98 | 26080 | 744 | n/a | 0 | 0 | n/a | 23.4% | 100.0% | n/a | 26980 | 24.2% |
| Apr-98 | 31570 | 720 | n/a | 0 | 0 | n/a | 29.2% | 100.0% | n/a | 32454 | 30.1% |
| May-98 | 32370 | 744 | n/a | 0 | 0 | n/a | 29.0% | 100.0% | n/a | 33227 | 29.8% |
| Jun-98 | 13280 | 720 | n/a | 25 | 0 | n/a | 12.3% | 96.5% | n/a | 13932 | 12.9% |
| Jul-98 | 17600 | 744 | n/a | 111 | 0 | n/a | 15.8% | 85.1% | n/a | 17781 | 15.9% |
| Aug-98 | 22260 | 744 | n/a | 54 | 0 | n/a | 19.9% | 92.7% | n/a | 22465 | 20.1% |
| Sep-98 | 21790 | 720 | n/a | 0 | 0 | n/a | 20.2% | 100.0% | n/a | 22001 | 20.4% |
| Oct-98 | 23130 | 744 | n/a | 2.5 | 0 | n/a | 20.7% | 99.7% | n/a | 24984 | 22.4% |
| Nov-98 | 10310 | 720 | n/a | 0 | 0 | n/a | 9.5% | 100.0% | n/a | 10937 | 10.1% |
| Dec-98 | 14520 | 744 | n/a | 0 | 2 | n/a | 13.0% | 99.7% | n/a | 17623 | 15.8% |
| Tot-98 | 258,590 | 8,760 | n/a | 193 | 2 | n/a | 19.7% | 97.8% | n/a | 270,130 | 20.6% |
| Jan-99 | n/a | 744 | n/a | 0 | 0 | 1 | n/a | 100.0% | 99.9% | 21,410 | 19.2% |
| Feb-99 | n/a | 672 | n/a | 0 | 0 | 0 | n/a | 100.0% | 100.0% | 23,310 | 23.1% |
| Mar-99 | 28,014 | 744 | 566 | 1 | 0 | 1 | 25.1% | 99.8% | 99.8% | 29,590 | 26.5% |
| Apr-99 | 25,788 | 720 | 532 | 0 | 0 | 0 | 23.9% | 100.0% | 100.0% | 26,920 | 24.9% |
| May-99 | 18,545 | 744 | 489 | 0 | 0 | 0 | 16.6% | 100.0% | 100.0% | 19,980 | 17.9% |
| Jun-99 | 12,726 | 720 | 412 | 0 | 0 | 1 | 11.8% | 100.0% | 99.9% | 14,940 | 13.8% |
| Jul-99 | 18,716 | 744 | 437 | 0 | 0 | 1 | 16.8% | 100.0% | 99.9% | 20,680 | 18.5% |
| Aug-99 | 11,465 | 744 | 416 | 0 | 3 | 1 | 10.3% | 99.6% | 99.5% | 12,730 | 11.4% |
| Sep-99 | 27,451 | 720 | 496 | 0 | 21 | 2 | 25.4% | 97.0% | 96.8% | 29,620 | 27.4% |
| Oct-99 | 25,998 | 744 | 518 | 9 | 4 | 5 | 23.3% | 98.3% | 97.7% | 27,530 | 24.7% |
| Nov-99 | 12,374 | 720 | 303 | 0 | 50 | 2 | 11.5% | 93.1% | 92.8% | 12,290 | 11.4% |
| Dec-99 | 34,448 | 744 | 593 | 0 | 8 | 0 | 30.9% | 99.0% | 99.0% | 34,780 | 31.2% |
| Tot-99 | 215,525 | 8,760 | 4,762 | 10 | 86 | 11 | 16.4% | 98.9% | 98.8% | 273,780 | 20.8% |
| Jan-00 | 22,524 | 744 | 438 | 0 | 0 | 0 | 20.2% | 100.0% | 100.0% | 21,080 | 18.9% |
| Feb-00 | 13,961 | 696 | 426 | 0 | 0 | 0 | 13.4% | 100.0% | 100.0% | 14,940 | 14.3% |
| Mar-00 | 31,152 | 744 | 570 | 0 | 13 | 0 | 27.9% | 98.3% | 98.3% | 31,070 | 27.8% |
| Apr-00 | 24,539 | 720 | 502 | 1 | 0 | 1 | 22.7% | 99.8% | 99.7% | 25,830 | 23.9% |
| May-00 | 12,867 | 744 | 411 | 0 | 80 | 0 | 11.5% | 89.2% | 89.2% | 13,070 | 11.7% |
| Jun-00 | 10,135 | 720 | 386 | 14 | 0 | 0 | 9.4% | 98.1% | 98.1% | 9,950 | 9.2% |
| Jul-00 | 14,257 | 744 | 456 | 0 | 0 | 1 | 12.8% | 100.0% | 99.9% | 16,400 | 14.7% |
| Aug-00 | 18,802 | 744 | 496 | 0 | 0 | 0 | 16.8% | 100.0% | 100.0% | 19,410 | 17.4% |
| Sep-00 | 20,404 | 720 | 544 | 2 | 0 | 0 | 18.9% | 99.7% | 99.7% | 20,602 | 19.1% |
| Oct-00 | 30,905 | 744 | 602 | 0 | 3 | 0 | 27.7% | 99.6% | 99.6% | 30,768 | 27.6% |
| Nov-00 | 19,963 | 720 | 402 | 0 | 1 | 0 | 18.5% | 99.9% | 99.9% | 19,420 | 18.0% |
| Dec-00 | 23,296 | 744 | 472 | 0 | 0 | 0 | 20.9% | 100.0% | 100.0% | 22,660 | 20.3% |
| Tot-00 | 242,805 | 8,784 | 5,705 | 17 | 97 | 1 | 18.4% | 98.7% | 98.7% | 245,200 | 18.6% |
| TOTAL | 1,720,618 | 64,704 | 30,953 | 950 | 1,882 | 1,155 | 17.7% | 95.6% | 93.8% | | |

| TABLE 3 ANNUAL PRODUCTION BASED ON REVENUE METERING (REVENUE METERING COMMENCED IN JULY 1994) | | | |
|--|--------------|-------------------------|---------------------------|
| Yukon Energy 150 kW Bonus Wind Turbine - Annual Production | | | |
| Year | Hours | Actual gross kWh | Actual gross C.F.% |
| 1994 | 8,760 | 254,429 | 19.4% |
| 1995 | 8,760 | 248,249 | 18.9% |
| 1996 | 8,784 | 242,855 | 18.4% |
| 1997 | 8,760 | 242,307 | 18.4% |
| 1998 | 8,760 | 270,130 | 20.6% |
| 1999 | 8,760 | 273,780 | 20.8% |
| 2000 | 8,784 | 245,200 | 18.6% |



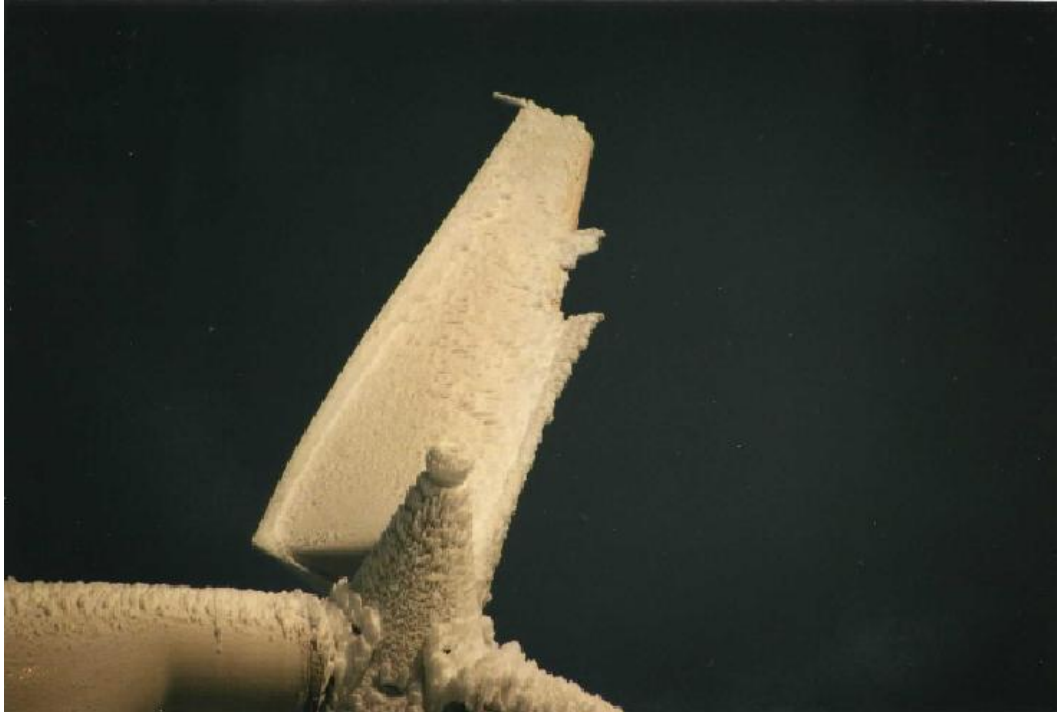
Photograph 1: Rime ice on monitoring equipment, only heated instruments stay clear



Photograph 2: the first wind turbine being winched up on hinged tip up tower



Photograph 3: turbine heavily iced, did not run through icing period



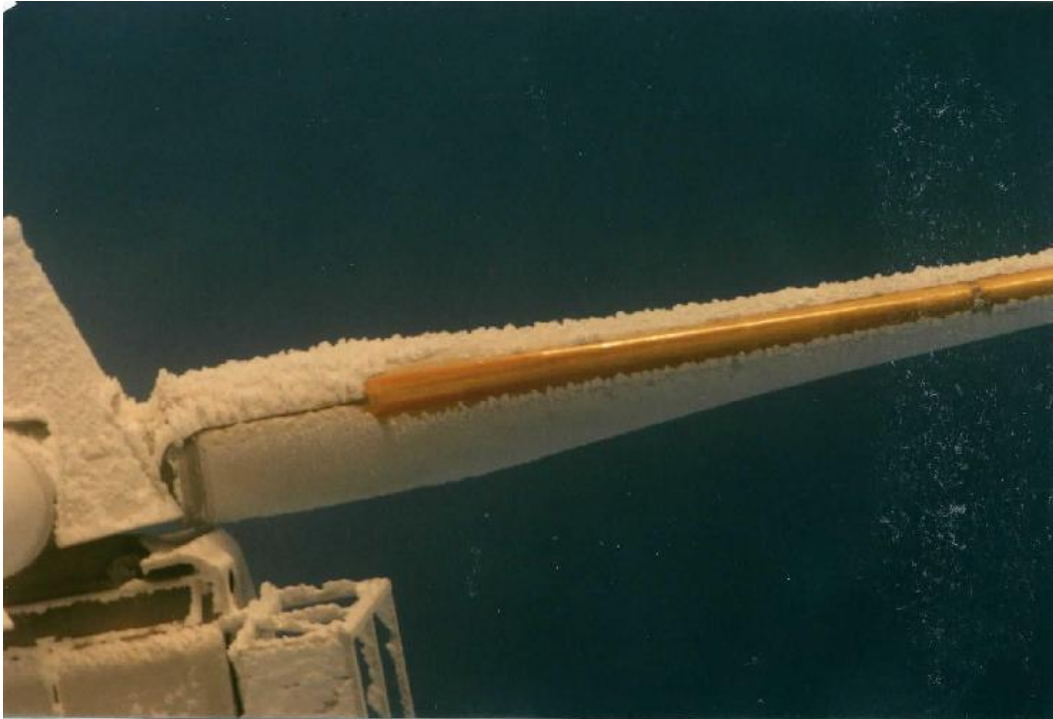
Photograph 4: wedge shaped ice builds up on the blades when running through icing events – leading edge heaters not working



Photograph 5: wedge shape build up from back, note clear back of blade – leading edge heaters not working



Photograph 6: in less severe rime icing the effect of the leading edge heaters extends past the leading edge



Photograph 7: in severe icing conditions the effect of the leading edge heaters does not extend as far



Photograph 8: accumulated ice shedding from black blades



Photograph 9: the second wind turbine being installed



Photograph 10: both wind turbines in place