

Noorvik and Kiana, Alaska Wind Power and Intertie Options Report



Photo: Doug Vaught

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This report was written by Douglas Vaught, P.E. of V3 Energy, LLC under contract to Northwest Arctic Borough and NANA Regional Corporation to explore wind power and electrical intertie development options for the villages of Noorvik and Kiana in northwest Alaska.

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Introduction

The Northwest Arctic Borough (NAB) and NANA Regional Corporation (NANA) are dedicated to enhancing and improving the traditional subsistence-focused lifestyle of residents of the Native villages of Noorvik and Kiana, both of which are located on the lower Kobuk River east of Kotzebue Sound in northwest Alaska. Key to this goal is reducing the high cost of living and enhancing the long-term sustainability of the region. A primary attribute affecting both issues is the high cost of energy. NAB and NANA understand that renewable energy is vitally important to reduce the overwhelming dependency of the region on fossil fuel for its energy needs, and that electrical power systems are more efficient when larger, hence an interest in interconnecting villages where possible and appropriate. NAB and NANA contracted V3 Energy, LLC to prepare this report exploring the resource potential of wind power in both communities and route options and economic benefits of an electrical intertie.

Executive Summary

Noorvik and Kiana are candidates to connect with an electrical transmission intertie due to their proximity on the Lower Kobuk River and the potential with an intertie to deliver renewable wind energy power to Kiana where otherwise it's not possible. The benefits of an intertie are significant given lower operating costs with switching the Kiana powerplant to standby status and concentrating future new power system infrastructure in Noorvik. The only viable intertie route passes near the long-operating Quarry Road met tower and this location is the recommended site for wind turbines to serve both communities.

Noorvik

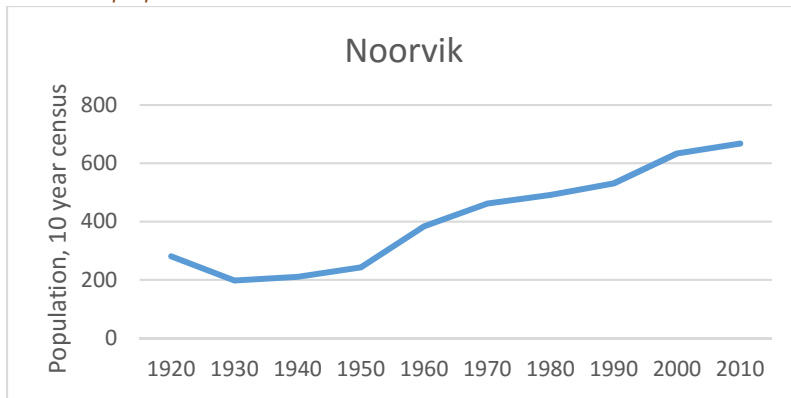
Noorvik means *"a place that is moved to."* The village was established by Kowagmiut Inupiat Eskimo fishermen and hunters from Deering in the early 1900's. The village was also settled by people from Oksik, which was located a few miles upriver. A post office was established in Noorvik in 1937 and the city government incorporated in 1964. Noorvik is primarily an Inupiat Eskimo community practicing a subsistence lifestyle.

Noorvik is located on the right bank of the Nazuruk Channel of the Kobuk River, 33 miles northwest of Selawik and 45 miles east of Kotzebue. The village is downriver from the 1.7 million acre Kobuk Valley National Park.

Noorvik is organized as a 2nd Class City in the Northwest Arctic Borough. The

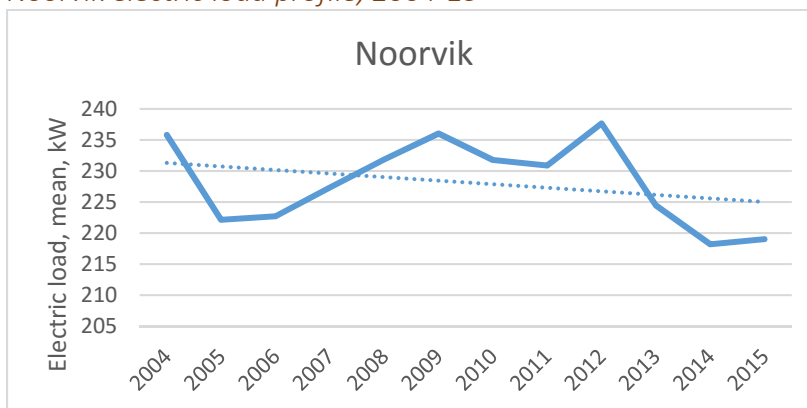
State Department of Labor estimated its population as 638 persons in 2015. Of these, 233 persons are under 16 years old with a median age of 22, indicating a young demographic profile and rapidly growing population.



Noorvik population census data*Noorvik Powerplant*

The electric utility in Noorvik is Alaska Village Electric Cooperative (AVEC). Electric power generation in the community is entirely by diesel-powered generators operating at 277/480 volts. The plant consists of three diesel generators: a Series 60 Detroit Diesel model S60K4c with a 363 kW Newage generator, a Cummins model K19G4 with a 499 kW Newage generator, and a MTU model 12V2000 with a 710 kW MAR generator. The generators are relatively old with commission years of 1997, 1999, and 2003 respectively, although overhauls are accomplished periodically. Total powerplant generator power capacity is 1,572 kW. A planned major power system upgrade is installation by Alaska Native Tribal Health Consortium (ANTHC) of a jacket water heat recovery system to serve the nearby school. Although heat recovery is critical for proper integration of wind power, the control system of the Noorvik powerplant is old and rudimentary and would also require major upgrade to accommodate wind power.

Although Noorvik's population is growing, the electric load, albeit looking at a shorter time period, has been on a decreasing trend over the past 12 years, noting though significant variation from year to year. A declining electric load shouldn't be interpreted as lack of growth or community vitality, however, but rather an indication of progress with replacement of inefficient electrical appliances and lights with high efficiency models.

Noorvik electric load profile, 2004-15

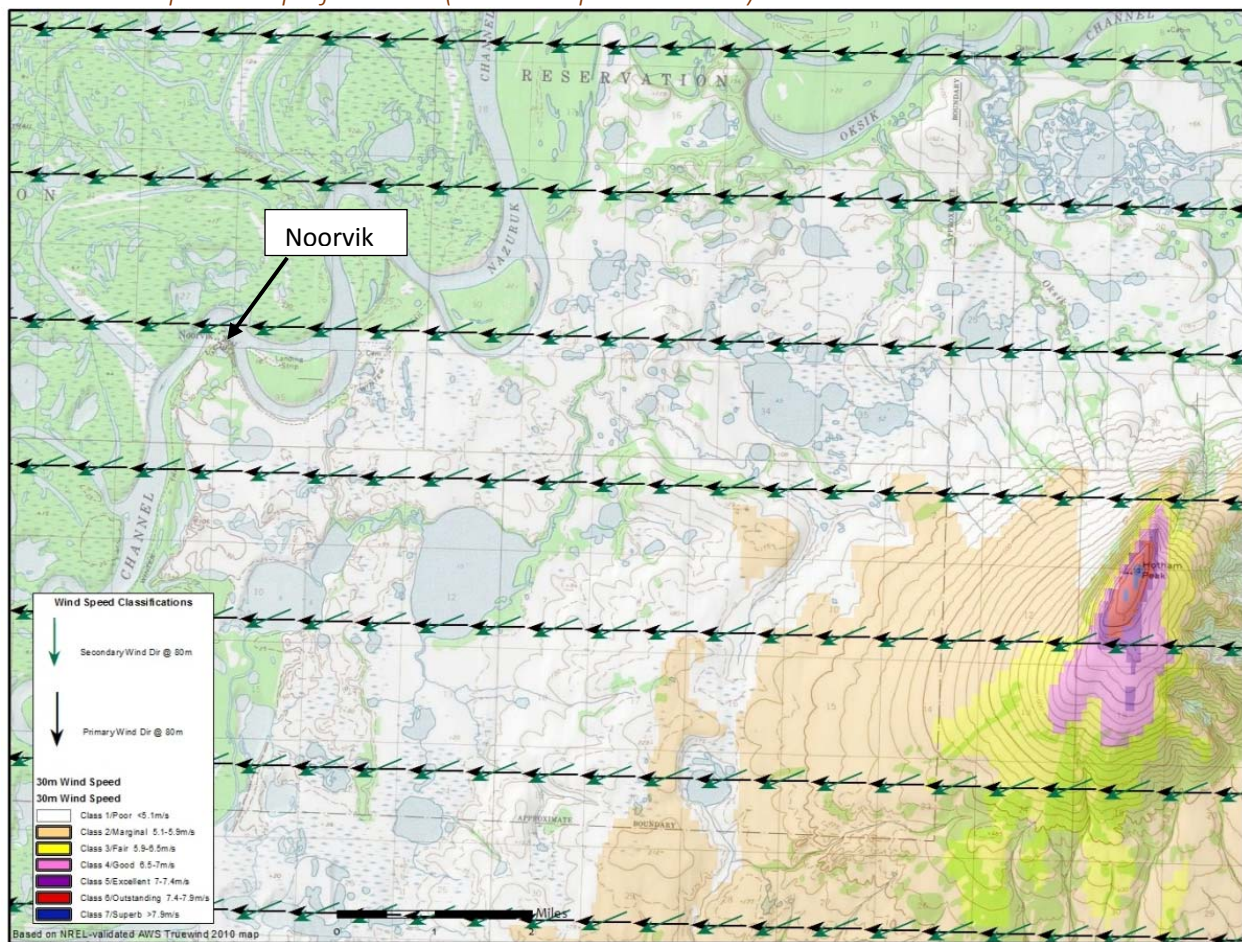
Noorvik Wind Resource

The wind resource in Noorvik has been extensively measured nearly continuously for over a decade. This reflects the potential for wind power in this large community so near Kotzebue with its successful wind farm, but also the uncertainty associated with a moderate wind resource, at least at sites near the village.

Although not available until 2011, wind site options and predicted wind classifications were informed by the Alaska high resolution wind map created by AWS Truepower's mesoscale modeling software (below). As one can see, Noorvik itself and the surrounding area are predicted as a Class 1 (poor) wind resource, although the higher terrain beginning approximately four miles east of the village are predicted to have a better wind resource with very high winds on Hotham Peak (red oval right center in the image below).

The Noorvik met tower wind study locations can be grouped as follows: near-village sites, Quarry Road site, and Hotham Peak. As one would expect, the near-village sites would be relatively easy and lower cost to develop but have a modest wind resource, the Quarry Road site is further away, but has road access and a significantly better wind resource than near the village. Hotham Peak has an outstanding predicted wind resource but is far away and would be expensive and difficult to develop.

AEA's Wind Speed Map of Noorvik (AWS Truepower model)



Near-village Sites

Two prospective wind power sites were equipped with met towers very near Noorvik: one on the runway of the old decommissioned airport, from 2008 to 2009, and another along the road to the new airport, from 2012 to 2014.

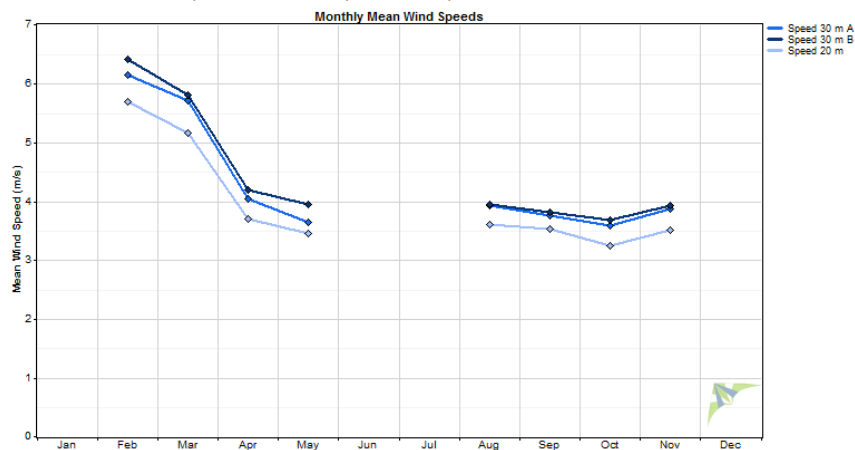
Noorvik village-area met tower sites



Old Airport Site

A 30 meter (98 ft.) met tower was erected in August, 2008 at the intersection of the main and cross-wind runways of the old airport, but unfortunately data recovery was hampered by a failed datalogger and subsequent delays and errors when replacing it. Ultimately only 6.5 months of data were recovered, which inferred a Class 1 to 2 wind resource as predicted by AWS Truepower. Data from the old airport met tower is documented in a wind resource assessment report, *Noorvik Wind Resource Report*, Sept. 2010.

Noorvik old airport monthly wind speeds

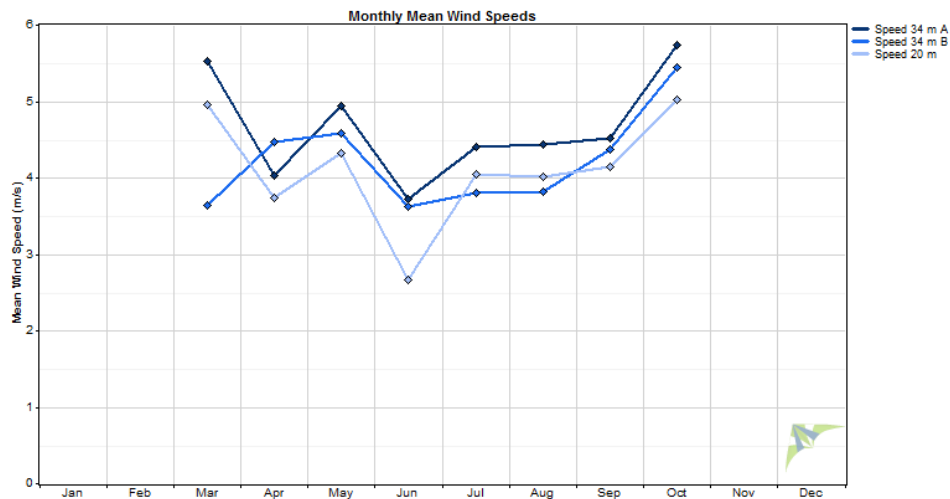


New Airport Site

A 34 meter (112 ft.) met tower was erected in a meadow just north of the airport access road, between the village and the airport apron, in July 2012 but as with the old airport site, errors and problems with data management resulting in a disappointing amount of data collection. Data was only collected from May through October, 2013; just 7.5 months' worth. Analysis of this data indicated a Class 1 wind resource, although because the windy winter months are missing, the data set is biased somewhat low.

Data from new airport met tower was never documented in a stand-alone wind resource assessment report, although elements of it are contained in other reports and analyses.

Noorvik new airport monthly wind speeds



Landfill Site

The landfill site was never truly a prospective wind power site in that a met tower was not installed at this location, but it was proposed as a compromise location in 2013 during the Coffman Engineering design project. The compromise was the landfill is midway between a village site, which the community opposed, and the Quarry Road site, which requires a 4-mile distribution connection. Not fully appreciated at the time, however, is that the landfill is directly in line with the Noorvik airport runway and sufficiently near the airport that a height obstruction such as a wind turbine would not be acceptable to the FAA, especially for non-precision instrument approach (area navigation, or RNAV) procedures. Another complication is the presence of ice-rich pingos in this area which would complicate wind turbine foundation design.

The salient problem though of the landfill area is that it is at similar elevation as Noorvik. Hence, the landfill as a wind turbine site, besides the airport proximity and pingo issues, would share the disadvantage of the village sites of a low wind resource and disadvantage of the Quarry Road site with a long distribution line extension requirement. In that sense, as a wind turbine site option the landfill area could be considered as less desirable than either.

Quarry Road Site

The wind resource at the Quarry Road met tower site, located along the quarry access road about 8 km (5 miles) due east of Noorvik, has been studied extensively. A met tower was erected at this location in September 2001 for the Maniilaq Association by Tribal Energy Association of Northwest Alaska (TREANA) and

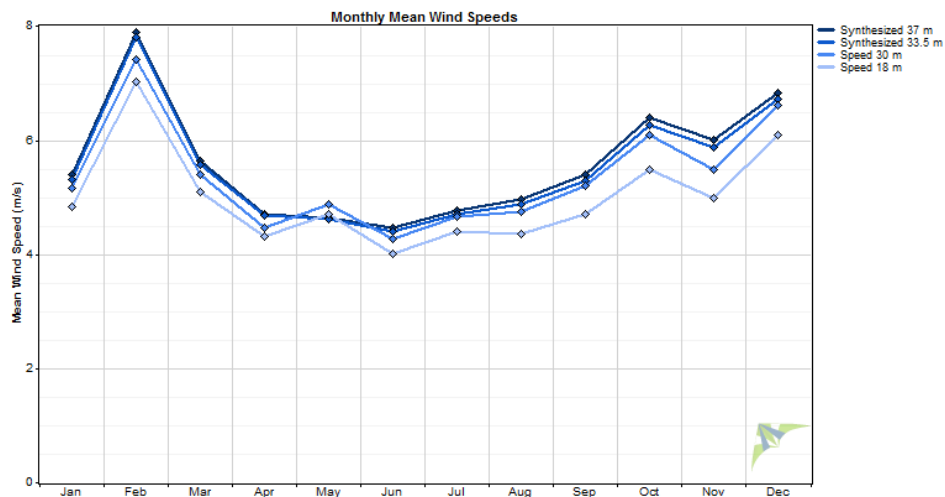
documented in a September 30, 2002 report submitted to the Administration for Native Americans (ANA) to complete their funding grant (see references). Unfortunately, although the met tower was operational for one year, the September 2002 report contained mostly powerplant and load growth information and only cursory summary data from the met tower.

Noorvik Quarry Road met tower site



An attempt was made several years ago to obtain the original data files from Maniilaq Association but that effort was only partially successful in that just five months of data were recovered. Because the September 2002 Maniilaq report inadequately described the wind resource at the site and given incomplete recovery of the data files from Maniilaq, it was decided in late 2010 to again erect a met tower at the Quarry Road site location. Because the original anchors were never removed and still secure, a 30 meter (98 ft.) met tower donated by Kotzebue Electric Association was erected at the exact location of the earlier Maniilaq met tower study.

Noorvik Quarry Road monthly wind speeds



The wind resource measured by the re-installed Quarry Road met tower was documented in a February 2012 report, *Noorvik, Alaska (Hotham Peak Quarry Road Site) Wind Resource Report*, with 15 months of good data. This report indicated a low wind power Class 4 wind resource by wind power density (although wind power Class 2 by wind speed, which validates the AWS Truepower modeling), with a 5.62 m/s (12.6 mph) mean annual wind speed at 30 meters above ground level. Measurement of turbulence at the site and modeling of extreme wind probability classifies the Quarry Road site as IEC 61400-1, 3rd ed., Class III-C. This means that turbulence is modest and extreme wind events are uncommon and of relatively low energy.

It should be noted, however, that the access road to the Quarry Road site is maintained only to the landfill during the winter months, which is about halfway from the airport turnoff to the site. Operational wind turbines at the Quarry Road site would likely necessitate additional snowplowing expense to maintain all-season access to wind turbines.

Hotham Peak

Interest in the wind power development potential of Hotham Peak began several years ago but earlier met tower efforts focused on presumably more developable sites. With measurement of a poor wind resource in and near Noorvik, and community opposition to wind turbines close to the village, and moderate winds at the Quarry Road site, Northwest Arctic Borough decided in 2014 to install a met tower near the summit of Hotham Peak to measure the wind resource and assess viability of the site for wind power development.

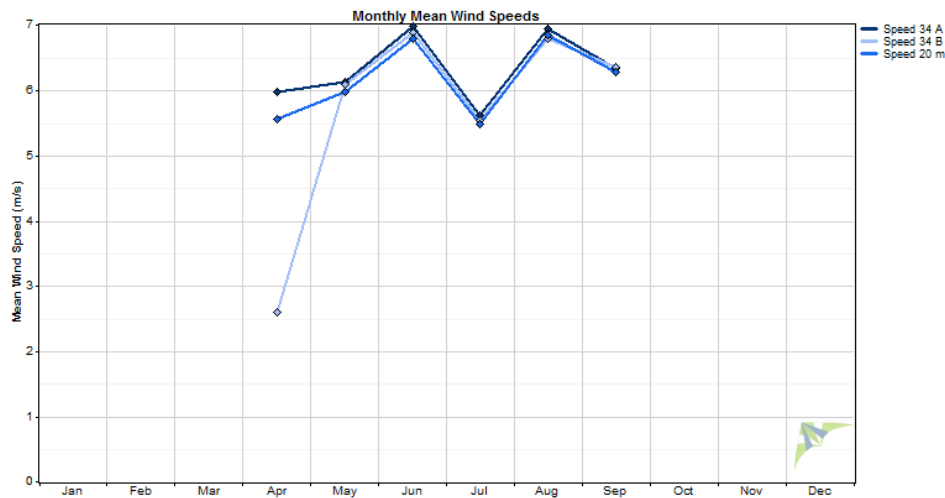
Hotham Peak met tower site



The Hotham Peak met tower was installed just inside the Selawik National Wildlife Refuge boundary (by special permission of USFWS) in April, 2015. At the same time, the Quarry Road met tower, which had not been operational for a few years but was still in place, was re-commissioned with new sensors. The intent was to concurrently measure the Hotham Peak and Quarry Road wind resources to directly compare wind power potential and suitability of each.

The site comparison effort was hampered unfortunately by two events: failure of the Quarry Road datalogger shortly after re-commissioning which was not corrected until mid-July, and collapse of the Hotham Peak met tower in an ice storm on September 30. This was very early season for a significant icing event and it should be noted that the evidence of significant icing was also observed in mid-April when the met tower was installed. Loss of the Hotham Peak met tower prevented analysis of icing frequency through the mid-winter months, but one can tentatively conclude that Hotham Peak is an ice-prone site and may prove operationally difficult for wind turbines. That said, the Hotham Peak met tower site does indeed have a very good wind resource, as one can see in the monthly wind speed graph (from tower installation in mid-April to tower collapse end of September).

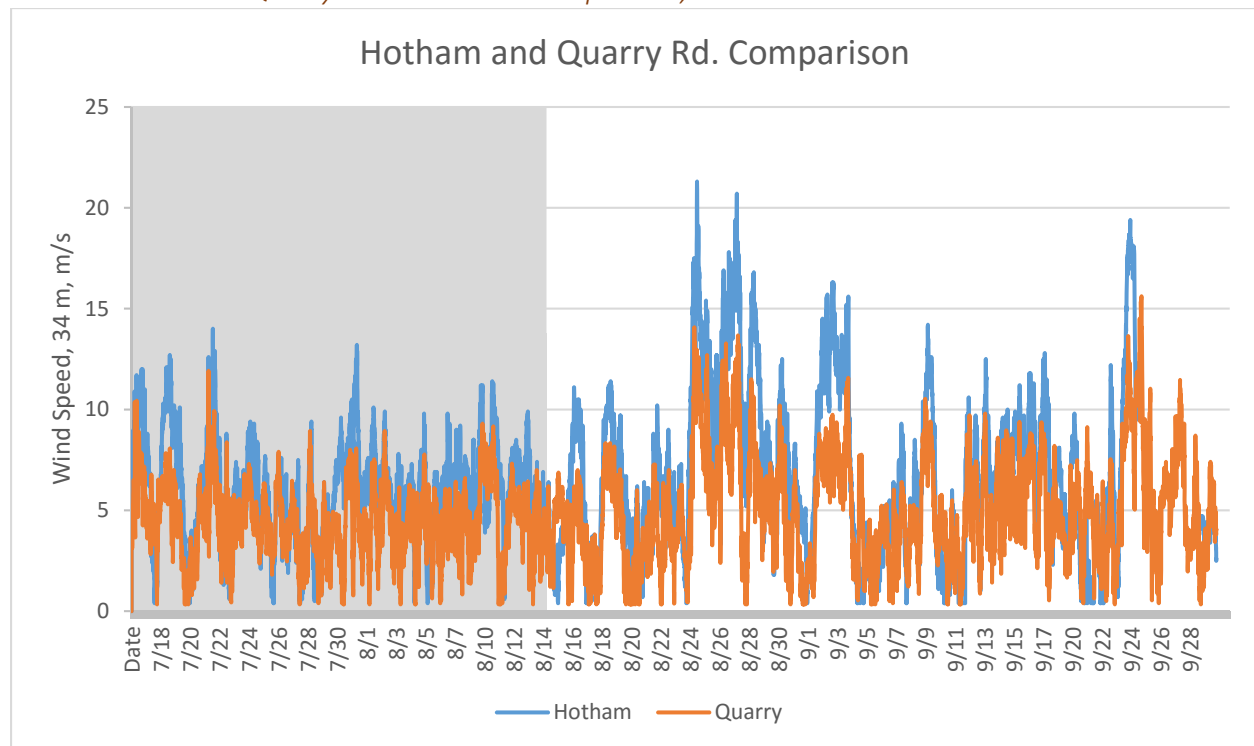
Noorvik Hotham Peak monthly wind speeds



As noted above, only 2.5 months of concurrent data between Hotham Peak and Quarry Road were obtained and given that July, August and September are lower wind summer and early autumn months, unfortunately they are of less interest than winter data. Still, the concurrent data that was obtained is valuable and as one can see in the table and graph below, clearly the Hotham Peak site has a superior wind resource compared to Quarry Road. Note in the table inclusion of average wind power production from a Northern Power Systems NPS100C wind turbine at a 34-meter hub height, recognizing of course that the turbine is only available at 22, 29, and 37-meter hub heights.

Hotham Peak and Quarry Road met towers, comparison table

Month	Hotham Peak		Quarry Road	
	Wind Speed, m/s	NPS100C Power, kW	Wind Speed, m/s	NPS100C Power, kW
7	5.83	26.0	4.41	10.6
8	6.95	33.2	4.77	15.4
9	6.34	26.4	5.02	18.2
Average	6.49	29.1	4.79	15.5

Hotham Peak and Quarry Rd. met tower comparison, 34 m level

Possibly with a much larger electric load, such as possible with an intertie to the village of Selawik, Hotham Peak can be re-considered as a possible site option for wind turbines, but future wind resource measurement will demand particular attention to survivability of the test equipment and possibly a more direct measurement of icing type and thickness to aid calculation of icing loss during wind turbine operations.

Recommended Noorvik Wind Project Site

Given the low wind measured and inferred wind resource near sites very near Noorvik, the access development and icing problems on Hotham Peak, the extensive wind data collected at the Quarry Road site, and the possibility of an electrical intertie to Kiana, the Quarry Road site area is recommended as the preferred location for wind turbines. But, the met tower site itself is not the optimum location at Quarry Road for wind turbines, as described below.

WAsP Analysis

WAsP (Wind Atlas Analysis and Application Program) and is PC-based software for predicting wind climates, wind resources and power production from wind turbines and wind farms and was used to model the Pitka's Point terrain and wind turbine performance.

WAsP software calculates gross and net annual energy production (AEP) for turbines contained within wind farms, such as an array of two or more turbines in proximity to each other. For a single turbine array, WAsP calculates gross AEP. With one turbine, net AEP is identical to gross AEP as there is no wake loss to consider.

Orographic Modeling

WAsP modeling begins with import of a digital elevation map (DEM) of the subject site and surrounding area and conversion of coordinates to Universal Transverse Mercator (UTM). UTM is a geographic coordinate

system that uses a two-dimensional Cartesian coordinate system to identify locations on the surface of Earth. UTM coordinates reference the meridian of its particular zone (60 longitudinal zones are further subdivided by 20 latitude bands) for the easting coordinate and distance from the equator for the northing coordinate. Units are meters. Elevations of the DEMs are converted to meters (if necessary) for import into WAsP software.

A met tower reference point is added to the digital elevation map, site locations identified, and a wind turbine selected to perform the calculations. WAsP considers the orographic (terrain) effects on the wind, including surface roughness and obstacles if specified, and calculates wind flow increase or decrease at each node of the DEM grid.

The WAsP mathematical model has a number of limitations, as does any model, including an assumption of wind regime at the turbine site same as the met tower reference site, prevailing weather conditions are stable over time, and surrounding terrain at both sites sufficiently gentle and smooth to ensure laminar, attached wind flow. WAsP software does not model turbulent wind flow resulting from sharp terrain features such as mountain ridges, canyons, shear bluffs, etc. For that, computational fluid dynamics (CFD) modeling is necessary.

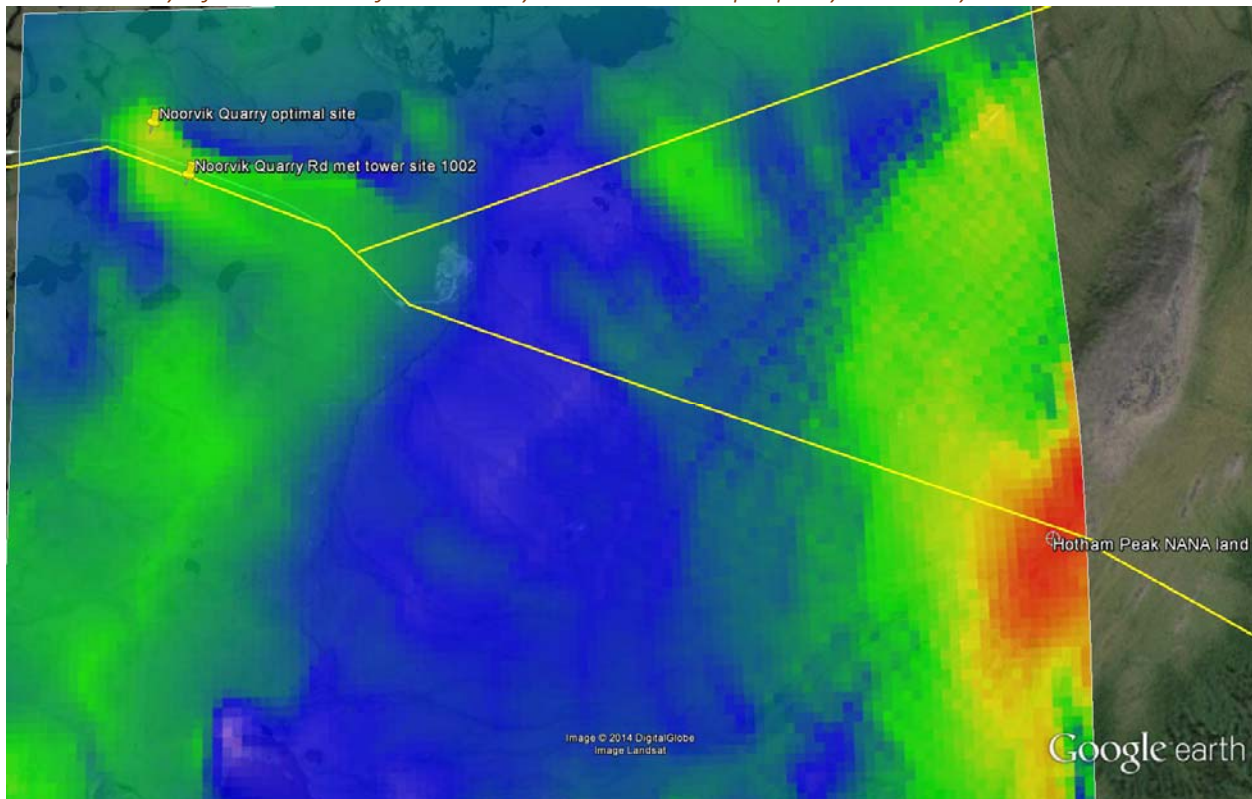
Noorvik WAsP Model

With recent digital elevation maps available from the National Elevation Database, using the Quarry Road met tower as the wind atlas reference point for the WAsP model, and with the new Northern Power NPS 100C-24 wind turbine for comparison, the software was set up to estimate annual energy production at several sites as indicated below. Note that WAsP assumes 100 percent net annual energy production (AEP), which for project planning should be reduced to reflect maintenance, icing, wake loss, etc. For AEA-funded projects, an assumption of 80 percent net AEP is typical.

Noorvik area site comparison by WAsP wind flow modeling, 100% net AEP

Site	Wind Speed at 37 meters (m/s)	Power Density at 37 meters (STP) (W/m ²)	NPS 100C-24 Annual Energy Production (MWh/yr)	NPS 100C-24 Capacity Factor (%)	AEP compared to Quarry Road met tower site
Quarry Rd. met tower site	5.66	326	257.4	29.3	-
Quarry Rd. optimal site	5.87	362	271.3	30.9	1.05
Landfill site	5.48	301	243.7	27.8	0.95
New Airport site	5.49	302	244.6	27.9	0.95
Hotham Peak site	6.72	596	314.9	35.9	1.22

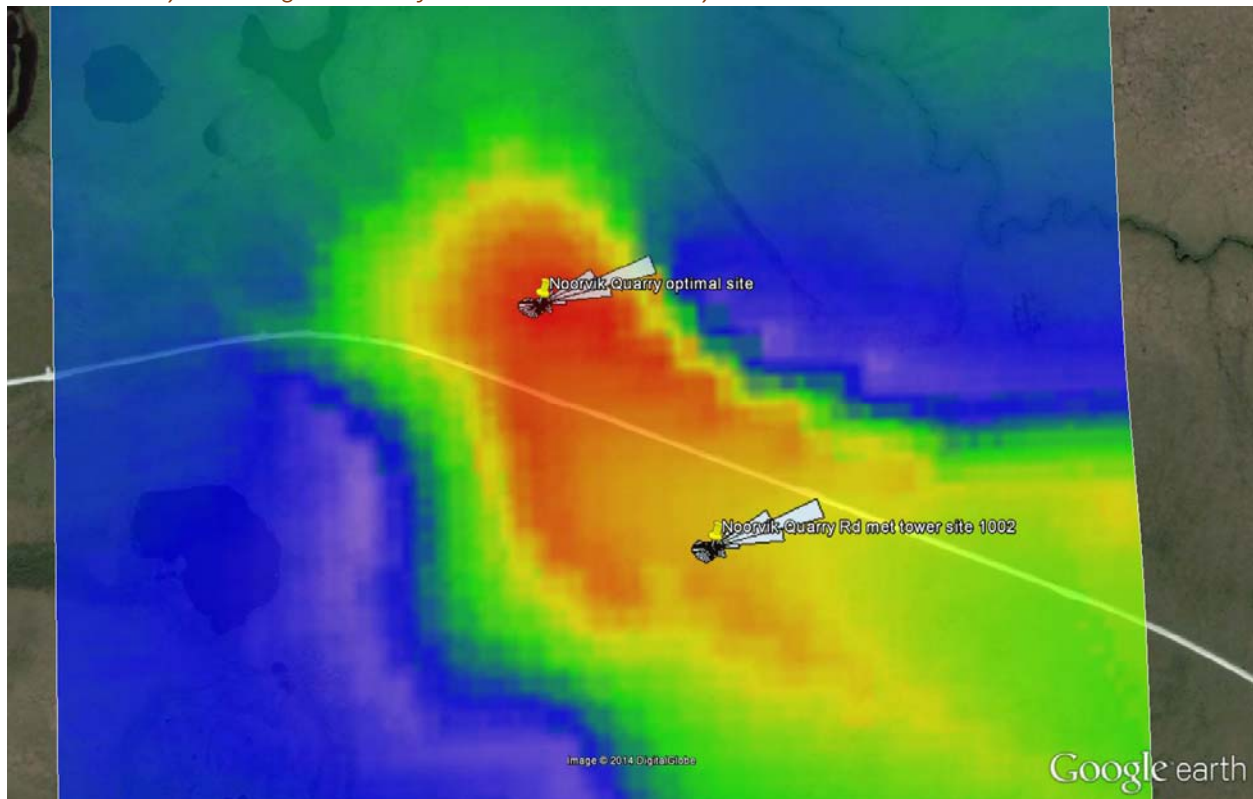
Note that energy production of a NPS 100C-24 turbine on NANA land on Hotham Peak models very well, as discussed earlier in this report, but this rotor turbine variant is optimized for lower wind speeds and may not actually be suitable for the site. Comparing to the 2.5 months of concurrent Hotham Peak and Quarry Road met tower data, Hotham Peak may be yet more energetic than predicted by WAsP modeling.

WAsP overlay of turbine AEP from Quarry Road to NANA property boundary on Hotham Peak

Note: yellow lines indicate prospective intertie routes to Kiana and Selawik

Site options near the Quarry Road met tower location, as shown in the preceding site comparison table, indicate that the met tower was not located at the most optimal wind location on Quarry Road hill. WAsP modeling shows that the nose of the hill, approximately 550 meters northwest of the met tower, is a more optimal location with estimated turbine annual energy production about five percent higher than at the met tower site itself.

Note that WAsP software allows one to graph at high calculation node resolution to observe variation of wind speed, wind power density, turbine annual energy production and other variables over a small area. Combined with a Google Earth overlay and inclusion of predicted wind frequency roses, this allows one to visualize wind flow from a geomorphology perspective. This helps with site selection and increases confidence that site location and wind turbine layout will be optimal. High resolution WAsP modeling of the Quarry Road site area is shown below.

WAsP overlay on Google Earth of turbine AEP at Quarry Rd. met tower area

Noorvik Wind Power Planning History

Wind power planning in Noorvik began in 2001 with the Maniilaq study at Quarry Road hill, lay dormant for a number of years, and re-commenced in 2008 with installation of the met tower at the old airport. Feasibility studies to assess the economic potential of wind power culminated in 2012 with *Conceptual Design Report, Wind-Diesel Power System for Noorvik, Alaska*, by WHPacific. WHPacific recommended installing three remanufactured Windmatic wind turbines at the new Airport site, the latter which reflected AVEC's preference for a wind turbine site near the community, which would enable easy access during winter. As an alternative, WHPacific also recommended installing two Northern Power NPS100 turbines, also at the new airport site. WHPacific noted that a wind project would require an electric boiler connected to a heat recovery loop, which at the time did not exist but which since has been installed by ANTHC and is now operational.

The Maniilaq, V3 Energy, and WHPacific resource evaluation and feasibility work was followed in 2013 by a NWAB contract awarded to Coffman Engineering to design a wind power project for the community, in concert with companion design projects (awarded to WHPacific) for Deering and Buckland. Although the wind turbine of choice for Deering and Buckland was the 100 kW Northern Power Systems NPS100, for Noorvik the utility (AVEC) wished to install a larger 225 kW Aeronautica wind turbine. Unfortunately, the project was not completed for a number of reasons, including a disagreement regarding project site location, suspension of market availability of the Aeronautica wind turbine, and lack of funding to construct a project considering that the Deering and Buckland projects were proceeding first and the overall budget ultimately could not accommodate all three.

Kiana

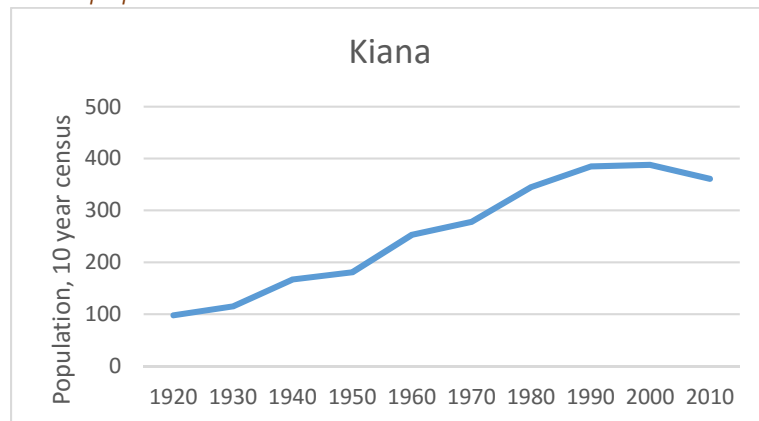
Katyaaq means “a place where rivers meet.” It was established long ago as the central village of the Kobuk River Kowagmiut Inupiat Eskimos. In 1909, it became a supply center for the Squirrel River placer mines. A post office was established 191 and the city government incorporated in 1964. Prior to the formation of the Northwest Arctic Borough in 1976, the Bureau of Indian Affairs high school in Kiana taught students from Noatak, Shungnak, Kobuk, and Ambler, who boarded with local residents.

Kiana is located on the north bank of the Kobuk River, 57 air miles east of Kotzebue and approximately 31 km (19 miles) upriver from Noorvik. The village is downriver from the 1.7 million acre Kobuk Valley National Park.



Kiana is organized as a 2nd Class City in the Northwest Arctic Borough. The State Department of Labor estimated its population as 425 persons in 2015. Of these, 35% are under 19 years old, indicating a young demographic profile. Note however that the population of Kiana has plateaued and declined slightly since 1990.

Kiana population census data

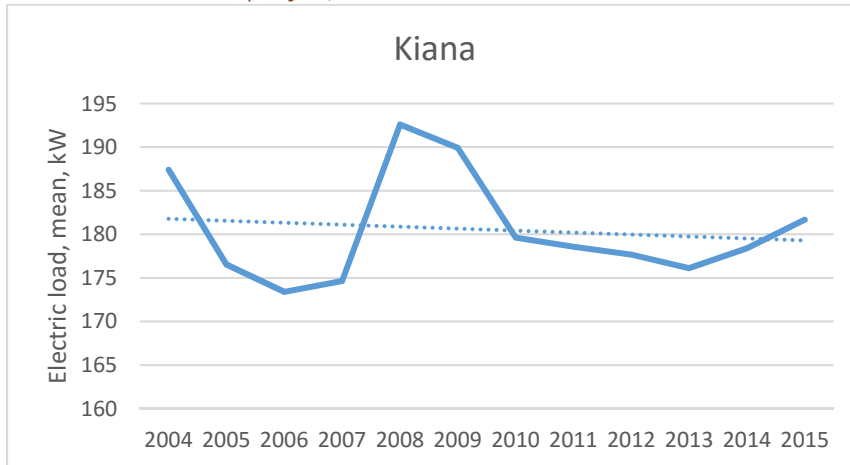


Powerplant

The electric utility in Kiana is Alaska Village Electric Cooperative. Electric power generation in the community is entirely by diesel-powered generators operating at 277/480 volts. The plant consists of three diesel generators: a Series 60 Detroit Diesel model S60K4c with a 314 kW Newage generator, a Cummins model KTA1150 with a 350 kW Kato generator, and a Cummins model KTA19G4 with a 499 kW Newage generator. The generators are relatively old with commission years of 2001, 1990, and 2000 respectively, although overhauls are accomplished periodically. Total powerplant generator power capacity is 1,163 kW.

Kiana's recent population growth is flat-to-declining and its electric load has been on a decreasing trend as well over the past 12 years, noting though significant variation from year to year. A declining electric load shouldn't be interpreted as lack of growth or community vitality, however, but rather an indication of progress with replacement of inefficient electrical appliances and lights with high efficiency models.

Kiana electric load profile, 2004-15



Kiana Wind Resource

Kiana is well inland, located along the banks of the Kobuk River, is heavily forested, and is surrounded by hilly and mountainous terrain, hence one would not expect a significant wind resource at or very near the village, and indeed this is true. A met tower has not been installed in or near Kiana, but reference to the Alaska high resolution wind map created by AWS Truepower's mesoscale modeling software is useful and enlightening.

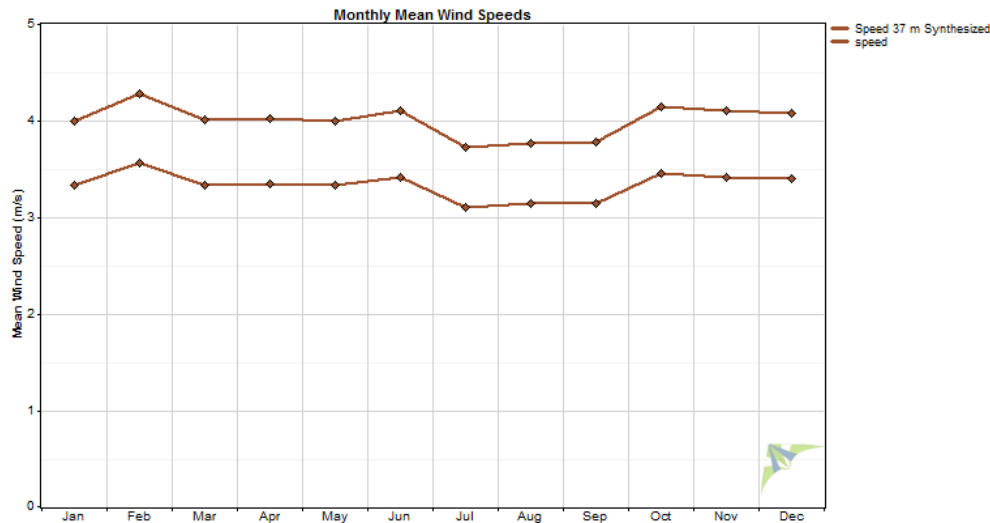
AWS Truepower model of Kiana; Google Earth overlay (tan indicates Class 2 winds; red Class 6)



Another valuable wind reference is the Kiana airport weather station (AWOS). Although AWOS and met tower data are not strictly comparable given variations in averaging periods, etc., over a long enough period

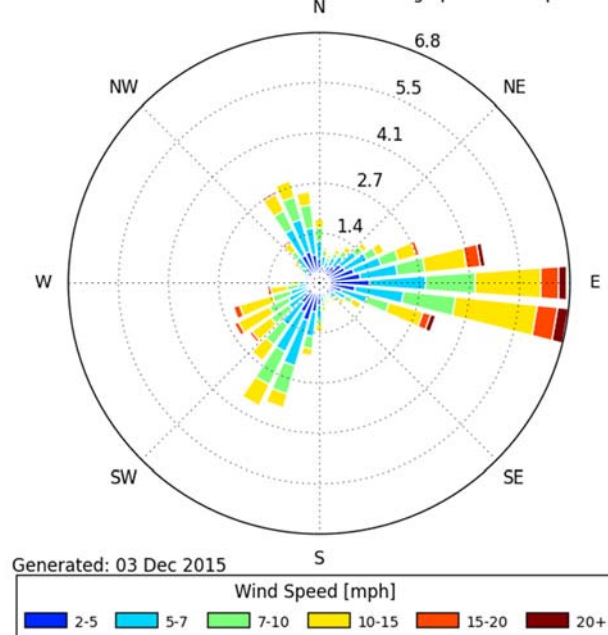
of time, the AWOS data is a very good substitute. Plus, although the AWOS wind sensor is only 10 meters of elevation above ground level, airport weather stations are located in well-cleared areas and hence the data is representative of the local area and hence very useful for wind flow modeling.

Kiana airport monthly wind speeds



Kiana airport wind rose

[PAIK] Kiana
Windrose Plot [All Year]
Period of Record: 01 Jan 1984 - 02 Dec 2015
Obs Count: 73991 Calm: 26.1% Avg Speed: 5.9 mph



WAsP Model

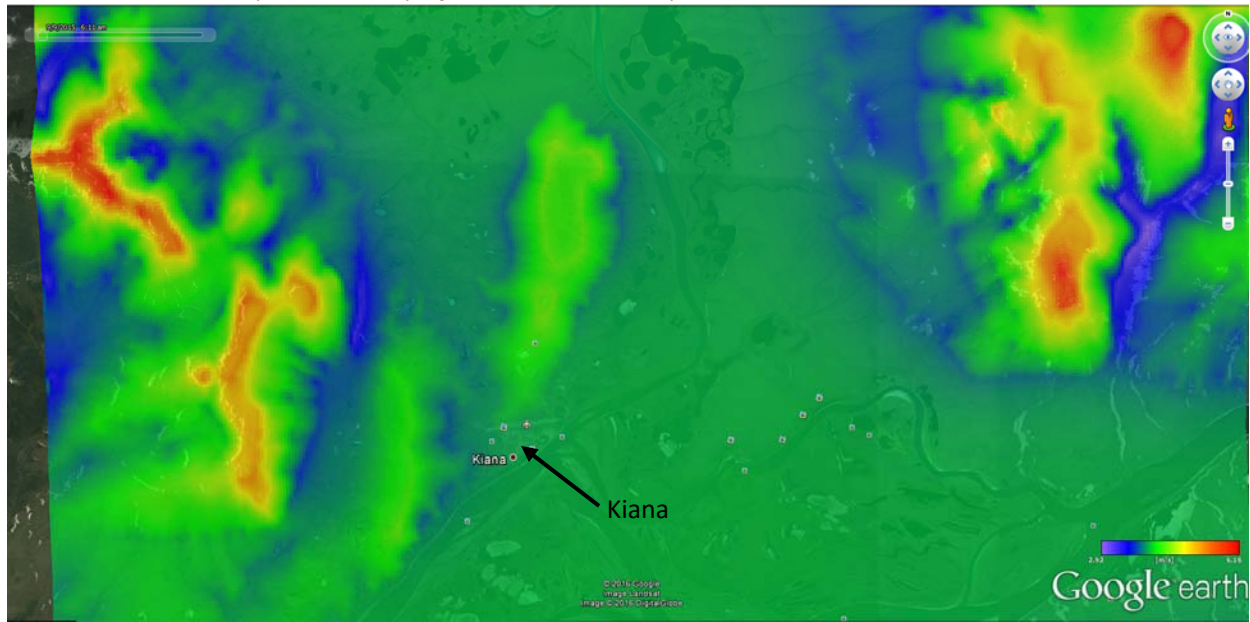
Using seven years of Kiana airport AWOS data, extrapolated from the 10 meter ASOS sensor height to 37 meters (the hub height of a Northern 100 wind turbine), WAsP software was used to generate a wind map of Kiana and vicinity, using methodology as noted earlier in this report with respect to Noorvik.

With reference to the following graph and interpreting its legend, wind speeds high enough for wind power development are yellow and red, which as one can see are fairly distant from Kiana. An exception is a north-south trending ridge approximately 2.5 miles directly west of the village. Lack of established access aside, this ridge could possibly be ideal for wind power development except for orientation of the airport runway, which aims directly at it. Constructing on this ridge would penetrate FAA-controlled airspace and permitting would be very difficult, resulting either in an outright unfavorable ruling, or if favorable, would require at a minimum an airport traffic pattern change to non-standard approach traffic to Runway 6 (from left to right-hand traffic). RNAV procedures may also require revision and minimum visibility altitudes may have to be increased, both of which, if required, would reduce the frequency of flights into Kiana. These changes would likely be required even to install a met tower on the ridge.

Interestingly, there is a plateau of higher ground immediately north of the sewage lagoon, which the WASP model predicts as a higher wind resource than in Kiana itself. Normally this might present a promising option for wind power development but unfortunately this area is shadowed from prevailing easterly winds by high terrain both east and west.

The WASP model validates the AWS Truepower wind classification map I had sent you in November. I will include all this in my report of course.

WASP model wind speed overlay of Kiana and vicinity



Kiana Wind Power Options

Although it is certainly possible of course to develop wind power in the vicinity of Kiana, the site options do not appear very promising. With respect to wind, Kiana is located in a calm wind bowl with higher winds limited to high terrain east and west of the village. Without existing roads and/or bridges to access these areas, development costs would be prohibitively expensive. High costs to develop access can be justified for a large enough project, but Kiana is a small community where wind power development costs must be minimal for a project to be economically beneficial.

Noorvik-Kiana Electric Intertie

A method to increase electric system efficiency and enhance the penetration and usability of a renewable energy generation source such as wind power is to increase the electric load. In isolated grid power systems, higher electric loads yield system stability and versatility with renewable energy options. Interconnecting two independent systems does not eliminate the need for a powerhouse in each village, but only one location – the primary – will be managed for day-to-day operations. A stand-by/emergency generator module will be maintained at the other – the secondary – location. The stand-by generator in the secondary location would be used as an emergency back-up power supply if the intertie or prime power plant should fail. With this operational structure in place, interties offer the following economic benefits:

- Lower capital costs per installed kilowatt
- Lower operating costs with the reduction of operating staff at the secondary location
- Lower maintenance costs with mechanics and technicians traveling to fewer locations
- Increased diesel efficiency during off-peak periods
- Increased economies of scale in bulk fuel storage costs
- Increased economies of scale for renewable energy through:
 - More generation capacity at one location
 - Increased usability during off-peak periods

Both Noorvik and Kiana are AVEC villages and given their proximity, were evaluated in an August 2014 report, *Intertie Options for Selected AVEC Villages*, that AVEC consultants (principally V3 Energy, LLC and Financial Engineering Company) and staff prepared for the Denali Commission. This report, however, considered a three-way electrical distribution intertie of Noorvik, Selawik and Kiana with the main, or base, power generation plant in Noorvik and conversion of the Selawik and Kiana powerplants to standby status. This was a difficult consideration in that the Selawik powerplant is relatively new and in much better present condition than the powerplant in Noorvik, but given that barge delivery to Noorvik is more certain and less expensive than to Selawik and with lower fuel prices in Selawik as a consequence, Noorvik was the preferred location for the primary powerplant.

Considering only Noorvik and Kiana as an intertie option, Noorvik is the obvious primary powerplant choice given that it is lower on the Kobuk River and the larger community of the two. Also, wind turbines serving the intertie, if installed, would be located in Noorvik as well, which consolidates energy generation to one community. In this scenario, the Kiana powerplant would be secondary and converted to standby status.

Methods and Assumptions

Analytical methods from the 2014 *Intertie Options for Selected AVEC Villages* report are used in this report and summarized below, but the reader may wish to consult the 2014 report for a fuller understanding of the project and its methodology.

The spreadsheets developed for the *Intertie Options for Selected AVEC Villages* report compare by benefit-to-cost ratio power generation: existing independent systems versus construction of an intertie. This analysis is carried further with an inclusion of wind generation and the possible scalable benefit of supplying renewable energy, specifically wind power, to a larger combined load. For each scenario – without wind power and with wind power – three discount rates are considered: non-discounted or 0%, 3% (AEA's Renewable Energy Fund

default, and 6% (more typical of traditional funding analysis). The result is benefit-to-cost ratios for each intertie defined by the following matrix (presented separately for the option of wind turbines).

Intertie economic analysis format

Wind Turbines	Discount Rate, %	Net Present Value		Benefit/Cost Ratio
		Without Intertie, \$M	With Intertie, \$M	
No	0			
	3			
	6			
Yes	0			
	3			
	6			

Replacement

An intertie is considered a 50-year project and the analysis spreadsheet is structured with net present value calculations referencing the selected discount rate. In general, capital costs for intertie construction, powerplant and bulk fuel upgrades, and wind turbine installation are incurred in the initial years of the project. As time goes on, however, machinery and equipment wear out and items must be repaired or replaced. The analysis spreadsheets are designed to capture this by considering a replacement period and replacement percentage for each major capital cost category with the option of varying the period and/or percentage for the power systems, with an additional option of varying the replacement period and replacement percentage differently without and with intertie. The default consideration of replacement period and percentage, which was used for the analysis in this report, is shown below.

Capital cost replacement period and percentages

	Without Intertie			With Intertie	
	Depreciation Period	Replacement Period	Replacement Percentage	Replacement Period	Replacement Percentage
Diesel Generation	15	15	25%	15	25%
Bulk Fuel Storage	30	30	25%	30	25%
Wind	20	20	40%	20	40%
Recovered Heat	15	20	75%	20	75%
Interconnections	30			30	10%

In general, diesel generators require a significant amount of maintenance and periodic overhaul throughout their service life with eventual replacement as they wear out and more efficient generators become available and/or more environmentally compliant generators are required. Newly constructed powerhouses, however, are designed as “platforms” for generators and associated switchgear and control systems and are expected to last many decades, perhaps even the full 50-year design life of the interties themselves. For these reasons, it is expected that 20 percent of the diesel generation power system, meaning principally the generators themselves and likely also associated switchgear, will be replaced every fifteen years, with or without the existence of an intertie.

The lifetime of new bulk fuel storage is longer, with an anticipated 30-year life before major replacement is required. Similar to diesel generation powerplants, the bulk fuel facility is considered a platform, with replacement of tanks or associated pumping/piping systems required on long time cycles. The bulk fuel facility itself though is expected to remain intact throughout the 50-year life of the intertie project.

Wind turbines are generally considered to have a 20-year operational life; beyond which they are replaced with new machines. Turbine foundations, however, assuming a new turbine of similar height, weight, and thrust characteristics, is reusable, hence an assumption of 50 percent turbine replacement every 20 years.

Distribution lines require periodic maintenance as does any other infrastructure, but in general require little refurbishment or overhaul. For this project, it is assumed that the intertie will require an upgrade of 10 percent of construction value every 30 years.

Inflation

The intertie analysis assumes an annual inflation rate of two percent applied to capital costs incurred in the future. For instance, if wind turbines are constructed in Year 1 with 50 percent replacement in Year 20, the capital cost in Year 20 would be the original capital cost times 50 percent times two percent annual inflation for 20 years. Mathematically: $\text{capital cost} \times 0.50 \times 1.02^{20}$.

Cost escalation of fuel through the 50-year project timeline follows a modification of the two percent inflation rate. Initial, or start point, fuel prices are based on Alaska Energy Authority's 2015 *EvaluationModelREF9Final (1)* Excel spreadsheet, community fuel oil price assumptions for electric sector with CO₂-equivalent allowance cost (social cost of carbon) included. With this start point, the intertie analysis spreadsheet escalates fuel cost at 2.0% for five years, 1.5% for the next five years, and 1.0% for the remaining 40 years of the project.

Discount rate values of 0%, 3% and 6% are applied to net present value calculations that summarize total energy generation costs, including initial and subsequent replacement capital costs, throughout the 50-year project life of the interties.

Note that fuel escalation assumptions discount rates can be manipulated in the intertie analysis spreadsheet. Beyond the fuel escalation rate, the Year 1 price of fuel is critical as future cost escalates from it. Should fuel prices jump significantly in the near future, to levels experienced as recently as a few years ago, the intertie spreadsheet would undervalue the benefit on an intertie.

Inflation and discount rates for intertie analyses

Cost Escalation (inflation)	
Non Fuel	2.00%
Fuel Escalation	
Years 1 - 5	2.00%
Years 6 - 10	1.50%
Year 11 and thereafter	1.00%
Discount Rate	0%, 3%, 6%

N-1 Criteria

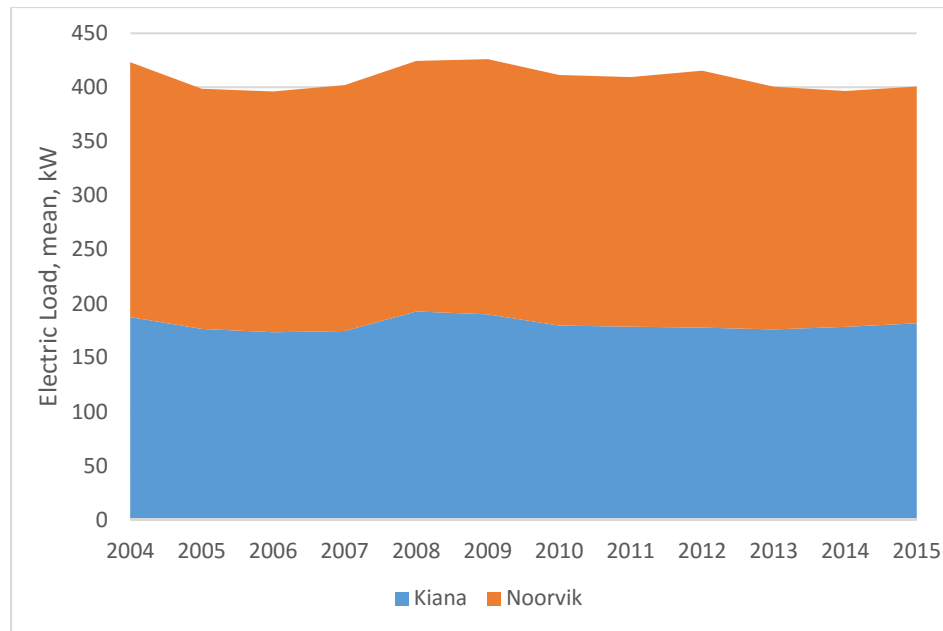
An isolated power generating grid should have sufficient capacity to meet the peak load with the largest unit out-of-service, known as N-1 criteria. In some situations, it may be advisable to meet N-2 criteria where peak load can be met the two largest generating units out-of-service. Each intertie project is evaluated considering capability of the base or primary village diesel generators to meet N-1 criteria in meeting the combined peak load of both villages. This analysis is quite conservative in that annual peak loads of the two villages are added to yield a combined peak load, but in reality it is unlikely that both villages would

experience their peak loads at exactly the same time. Still, the N-1 criteria analysis indicates readiness of the powerplant in the primary village to accept the electrical load of the secondary village.

Electric Loads and Generation

The diesel generators in the Noorvik powerplant have sufficient capacity at present to power both Noorvik and Kiana with consideration of N-1 criteria where the largest generation unit is out-of-service. Loss of the largest Noorvik generation unit, a 710 kW capacity MTU 12V2000 diesel generator, would result in two remaining diesel generators to meet load demand: a 363 kW Detroit Diesel S60K4c and a 499 kW Cummins K19G4. Combined capacity of these two diesel generators is 862 kW, which is just sufficient to meet a possible combined village peak load demand of approximately 822 kW. Note however in the graph below that average or mean load is substantially less, averaging approximately 400 kW on an annual basis. Although N-1 criteria may indicate a possible need to increase generation capacity in Noorvik when considering the potential of Noorvik and Kiana peak loads occurring simultaneously, typical electric loads are well within N-1 criteria of the present powerplant diesel generator configuration.

Noorvik and Kiana combined electric load trend



The N-1 analysis does not consider input of wind turbines and assumes that wind turbines, if installed, are off-line or wind energy is otherwise not available at the time of combined peak load demand. This analysis also does not consider line power loss along the intertie route.

Electrically connecting Noorvik and Kiana with Noorvik as the primary powerplant and Kiana as the secondary powerplant equipped with a standby system, the Noorvik powerplant will not necessarily require expansion with additional diesel generation capacity, but this may be warranted anyway considering the age of the units and the present antiquated powerplant control system. Note, however, that the economic analysis assumes replacement of the Noorvik powerplant.

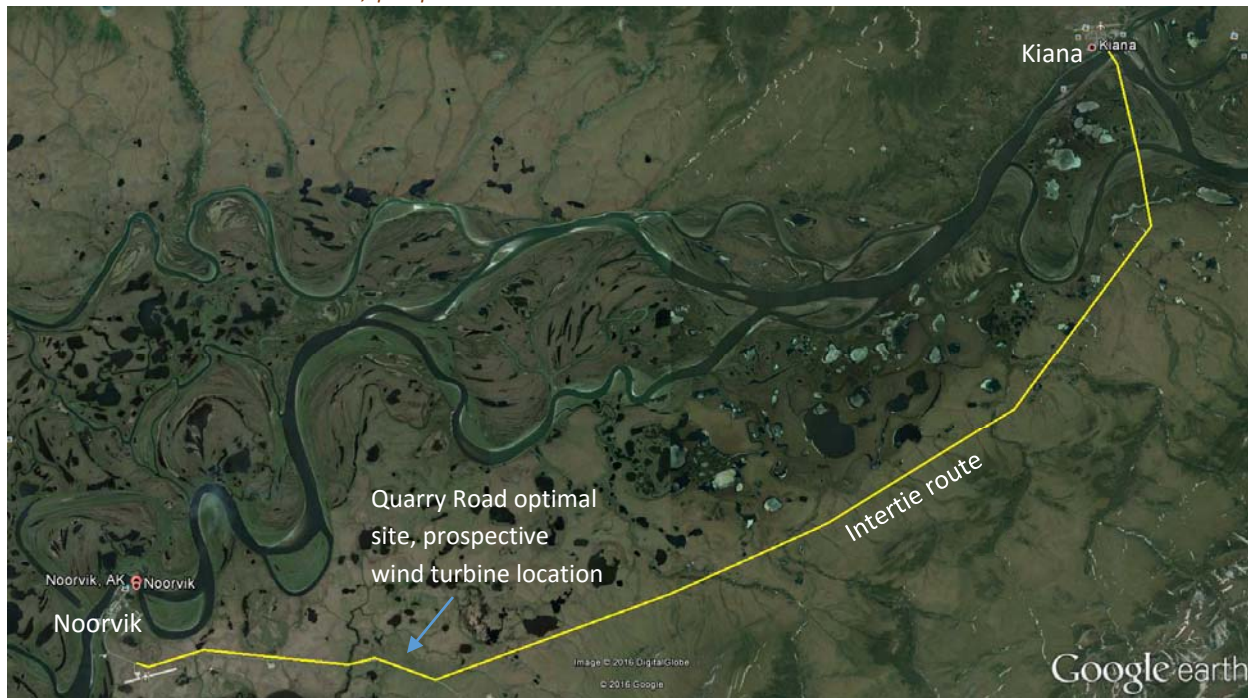
Noorvik and Kiana generation N-1 data

Generator	Noorvik		Kiana		Intertied (Noorvik as base powerplant)	
	Installed Capacity (kW)	Year Installed	Installed Capacity (kW)	Year Installed	Installed Capacity (kW)	Year Installed
1	363		324		363	
2	499		350		499	
3	710		499		710	
Total	1,572		1,173		1,572	
Avg Load (kW)	225		185		410	
Peak Load (kW)	446		376		822	
Firm Capacity (N-1)	862		674		862	

Intertie Route

The intertie routes to electrically connect Noorvik and Kiana would be comprised of a 5-mile route along the access road linking Noorvik to just past the wind power site on Quarry Road hill, plus an 18-mile cross-country route from a Quarry Road departure point about 0.5 mile east of the proposed turbine site to Kiana. The routing has been drawn only with access to Google Earth imagery to select upland type terrain to the extent possible to avoid excessively marshy land. At a point approximately 3.3 miles south of Kiana, however, the route must turn due north and cross a major slough of the Kobuk River, the Kobuk River valley, and the Kobuk River itself.

Note that the proposed Noorvik-Kiana route is tentative and does not consider land ownership, environmental, avian, construction and other considerations. Its intent is to indicate a likely best route between the communities and demonstrate the economic viability of a project. Should an intertie project be forwarded for serious consideration and planning, a much more detailed feasibility analysis would be appropriate.

Noorvik-Kiana intertie route, proposed*Noorvik-Kiana intertie route elevation profile*

Assumptions and Special Issues

This analysis assumes a new power plant at Noorvik with sufficient generation and fuel storage capacity to provide electricity by intertie to Kiana. Noorvik has sufficient land available for a sub-regional power plant and tank farm, including even an intertie to Selawik should that be considered at some point.

It is assumed that a combined Noorvik-Kiana powerplant will operate at higher efficiency than either standalone plant at present. This assumption is based more on replacement of the Noorvik generators with higher efficiency units than simply adding Kiana's electric load.

AVEC assumes non-fuel expense cost savings of \$140,000 per year when connecting two villages and shutting down one of the powerplants and converting it to standby status. This is mostly labor savings, but also includes powerplant consumables, maintenance, etc.

A delivered fuel price of \$4.11 per gallon in Noorvik and \$4.14 in Kiana is from Alaska Energy Authority's EvaluationModelREF9Final (1) Excel spreadsheet for the year 2018. This spreadsheet is used to evaluate and compare the long-term economic benefit of Renewable Energy Fund (REF) proposals and for that purpose contains fuel price estimates for 2015 through 2076. The price estimates include the price of fuel itself plus a

carbon dioxide equivalent allowance cost (i.e., carbon tax), which varies from \$0.47 in 2015 to \$2.79 in 2076. It should be noted, however, that the start point of AEA's fuel price estimates are historically low, even though they've been adjusted somewhat for that effect. Fuel prices were derived by the Alaska Center for Energy and Power (ACEP) and are documented in a June 2015 report, *Correlating Community Specific Rural Diesel Fuel Prices with Published Indices of Crude Oil Prices, And Potential Price Projection Applications*, available on the AEA website.

The intertie is assumed to cost \$325,000 per mile, which is based on recent STG, Inc. powerline construction experience in the Northwest Arctic Borough. Obviously though, some portions of the intertie route will be easier and less expensive to construct than others. For example, constructing power distribution along the Quarry Road in Noorvik will be fairly straightforward compared to crossing the Kobuk River near Kiana, which will be quite difficult and expensive.

The wind farm option is comprised of three Northern Power Systems NPS100C-24 wind turbines to serve Noorvik alone and six NPS100C-24 wind turbines to serve Noorvik and Kiana if intertied, all at the Quarry Road wind site. The NPS100C-24 is the most recent model of Northern Power's 100 kW wind turbine and when equipped with the 24-meter rotor is particularly well optimized for the moderate wind speeds measured at the project site.

This analysis was calculated with an assumption of a project start year of 2018 for all elements and options. This is not likely to be entirely true should a project proceed, but is a reasonable starting assumption.

Noorvik and Kiana cost assumptions, NPS100 turbines

	Without Intertie		With Intertie	
	Noorvik	Kiana	Noorvik	Kiana
Energy (MWh/yr)	1,976	1,618	3,626	
Fuel Price (\$/gal)	4.11	4.14	4.11	
Efficiency (kWh/gal)	12.25	12.98	13.00	
Non-fuel Expense (\$/yr)	\$487,121	\$366,040	\$713,161	
Powerplant Cap. Cost	\$5,000,000	\$5,000,000	\$5,400,000	\$750,000
Bulk Fuel Cap. Cost	\$6,800,000	\$2,550,000	\$6,800,000	
Wind Farm Cap. Cost	\$3,105,645	\$0	\$5,279,597	
Intertie Cap. Cost			\$7,475,000	

The following table documents the assumptions of the Noorvik-Kiana intertie benefit-to-cost spreadsheet model, highlights of which are listed in the cost summary table above.

Explanation of capital cost estimates (modified from AVEC's 2014 report to Denali Commission)

Village	Capital Cost Item	Cost Year	Basis
Without Intertie			
Noorvik	Powerplant	2018	Based on construction cost of new power plant in Stebbins, adjusted for on-grade vs. pile construction.
	Bulk Fuel Facility	2018	Based on 400,000 gal of required storage capacity at \$17.00/gallon for pile construction.

Village	Capital Cost Item	Cost Year	Basis
Kiana	Wind Farm	2018	Three NPS100C-24 wind turbines at the Noorvik Quarry Road site based on AEA's 2015 REF9 default cost rural wind of \$10,897/kW.
	Powerplant	2018	Estimate based on relocation of the powerplant on a pile or triodetic foundation, similar to the powerplant constructed in Brevig Mission in 2010.
	Bulk Fuel Facility	2018	Based on 150,000 gal of required storage capacity at \$17.00/gallon for pile construction.
	Wind Farm	n/a	A stand-alone wind farm in Kiana is assumed as not cost effective and/or developable.
With Intertie			
Noorvik	Powerplant	2018	Based on construction cost of new power plant in Stebbins, adjusted for on-grade vs. pile construction.
	Bulk Fuel Facility	2018	Based on 500,000 gal of required storage capacity at \$17.00/gallon for pile construction.
	Wind Farm	2018	Six NPS100C-24 wind turbines at the Noorvik Quarry Road site based on AEA's 2015 REF9 default cost rural wind of \$10,897/kW, but assumes a 15% discount to account for mobilization and other cost efficiencies of a six versus three-turbine installation.
Kiana	Powerplant	2018	Based on standard cost for a standby power module constructed on grade.
Noorvik-Kiana	Intertie	2018	Estimated Noorvik-to-Kiana project cost based on a 23-mile route averaging \$325,000 per mile.

Economic Analysis

The economic benefit of a distribution intertie connecting Noorvik and Kiana is presented below. As one can see, it is economically beneficial to intertie the two communities, even with relatively low fuel prices at present. As one would expect, the economic benefit decreases with an increasing discount rate as the benefits of the project are spread evenly over fifty years, but the costs are primarily borne in the early years of the project.

Noorvik-Kiana intertie 50-year economic benefit, without wind power

Wind Turbines	Discount Rate, %	Net Present Value		Benefit/Cost Ratio
		Without Intertie, \$M	With Intertie, \$M	
No	0	214.2	199.0	1.08
	3	109.6	103.5	1.06
	6	69.1	66.4	1.04

Installing wind turbines, whether serving Noorvik alone without an intertie or serving Noorvik and Kiana with an intertie is financially beneficial. Wind turbines as a component of an intertie project have a higher

economic benefit because for two reasons: a larger wind project has a lower capital cost per kW installed capacity due to design, mobilization and other efficiencies; and the benefits of wind can apply to Kiana too. As noted earlier, Kiana cannot be developed for wind power, but an intertie makes wind power for Kiana possible.

Wind turbine energy production is assumed as 80 percent net AEP; in other words, 20 percent of potential energy generation is lost due to maintenance, icing, wake, faults, and other loss factors. Note that the assumption of three wind turbines serving Noorvik and six wind turbines serving Noorvik-Kiana is based on a general goal of approximately 30 to 35 percent wind power penetration (penetration is discussed in the following section of this report).

Noorvik-Kiana intertie 50-year economic benefit, with wind power

Wind Turbines	Discount Rate, %	Net Present Value		Benefit/Cost Ratio
		Without Intertie, \$M	With Intertie, \$M	
Yes	0	208.9	185.9	1.12
	3	108.0	98.8	1.09
	6	69.1	65.1	1.06

Higher Fuel Costs

Fossil fuel energy costs are at a low ebb in their cyclical nature, which is naturally reflected in ACEP's June 2015 fuel price report, even though they employed sophisticated algorithms to moderate that effect. The details of ACEP's analysis is beyond the scope of this report, but for argument's sake, one could consider the economic benefit of an intertie or intertie-wind power project where the start point of fuel prices are much higher and escalate over time at the fuel price inflation rate noted earlier. For that, a 50% price increase is assumed for the start or base year of 2018, resulting in fuel prices of \$6.16 in Noorvik and \$6.21 in Kiana. As the table below indicates, the benefit/cost ration of an intertie project, while still beneficial, decreases slightly as high fuel costs overwhelm benefits of the project.

Noorvik-Kiana intertie 50-year economic benefit, 50% higher fuel cost, without wind power

Wind Turbines	Discount Rate, %	Net Present Value		Benefit/Cost Ratio
		Without Intertie, \$M	With Intertie, \$M	
No	0	256.3	240.3	1.06
	3	129.8	123.3	1.05
	6	80.7	77.8	1.04

With wind power, however, whether serving Noorvik alone or serving both Noorvik and Kiana via an intertie, the economic benefits of reduced fuel consumption make a solid positive impact due to the avoided usage of very expensive fossil fuel.

Noorvik-Kiana intertie 50-year economic benefit, 50% higher fuel cost, with wind power

Wind Turbines	Discount Rate, %	Net Present Value		Benefit/Cost Ratio
		Without Intertie, \$M	With Intertie, \$M	
Yes	0	244.9	215.1	1.14
	3	125.2	112.7	1.11
	6	78.9	73.1	1.08

Wind Turbine Option – EWT DW900

Selection of the Northern Power Systems NPS100C-24 wind turbine for the Quarry Road site, as previously stated, is based on AVEC's long operational history with the company, its suitability for the wind regime, the advantages of turbine redundancy, and a renewable energy penetration goal of 30 to 35 percent wind power. But, the NPS100 wind turbine is a limiting choice in that the 100 kW power capacity is low for a combined Noorvik and Kiana load (if intertied).

In recent years Northern Power Systems had indicated an intention to develop a 350 kW direct-drive wind turbine with essentially the same design characteristics as the NPS100, but market changes, mostly in Europe, forced reconsideration of that plan. Northern's decision has left a large hole in the village wind power market with only two realistic options for new models of the valued direct-drive generator design: the 100 kW Northern Power NPS100 and the 900 kW EWT Directwind.

EWT DW900 kW wind turbine has three rotor options, 52, 54 and 61 meters; and four hub height options, 35, 45, 50, and 75 meters (the 61-meter rotor is brand new to the market however and it's not clear at present that it is offered on all tower options). The advantage of the EWT DW900 is that it is a sophisticated design, is well supported in Alaska, and several models are operational in the state, notably for Noorvik and Kiana there are two in the nearby hub community of Kotzebue.

A 900 kW wind turbine, however, would have 50 percent higher installed capacity in an intertied Noorvik-Kiana system than the six NPS100C-24's modeled in the previous section and as such, would generate well above the approximately 33 percent wind penetration target. With this, an EWT DW900 could be considered a high penetration wind system, even if maintaining an operationally conservative diesels-on approach.

An operational option for the EWT DW900 is that can be setpoint-controlled; in other words, output can be command limited to as low as 250 kW through blade pitch manipulation. This can be advantageous at times where electrical and thermal load demands are too low to absorb the power potential of the turbine in the instantaneous wind environmental. For the following analysis, however, the EWT DW900 is modeled at optimum power generation at all times with sufficient thermal (heat) load demand to absorb excess energy not demanded by the electric load. For this to be true at all times, it is likely that water treatment plants in both Noorvik and Kiana plus possibly also the schools would require connection to the recovered heat system (in Noorvik only) or a remote node electric boiler arrangement.

For this analysis, a 54-meter rotor is modeled at a 75-meter hub height, which is identical to the EWT turbine configuration in Kotzebue. While installed cost of the Northern Power turbines is estimated at AEA's REF9 capital cost of \$10,897/kW of installed capacity for rural wind projects, the EWT capital cost is estimated at AEA's REF9 cost for urban or large-scale (>1,000 kW) cost of \$5,801/kW of installed capacity, or \$5.22 million. Thus, model inputs are per the table below and note Noorvik and Kiana fuel prices per AEA's projected 2018 costs in their REF9 Excel spreadsheet.

Noorvik and Kiana cost assumptions, EWT wind turbine option

	Without Intertie		With Intertie	
	Noorvik	Kiana	Noorvik	Kiana
Energy (MWh/yr)	1,976	1,618	3,626	
Fuel Price (\$/gal)	4.11	4.14	4.11	
Efficiency (kWh/gal)	12.25	12.98	13.00	
Non-fuel Expense (\$/yr)	\$487,121	\$366,040	\$713,161	
Powerplant Cap. Cost	\$5,000,000	\$5,000,000	\$5,400,000	\$750,000
Bulk Fuel Cap. Cost	\$6,800,000	\$2,550,000	\$6,800,000	
Wind Farm Cap. Cost	\$3,105,645	\$0	\$5,220,900	
Intertie Cap. Cost			\$7,475,000	

One EWT DW54-900 wind turbine at a 75-meter hub height (at the Quarry Road site), assuming equivalent 80% net annual energy production, generates approximately 40 percent more energy than six NPS100C-24 wind turbines at 37-meter hub heights. Because the modeled project capital cost for one EWT is equivalent to six NPS100's, the 50-year economic benefit is greater, as the table below indicates.

Noorvik-Kiana intertie 50-year economic benefit, EWT wind turbine option

Wind Turbines	Discount Rate, %	Net Present Value		
		Without Intertie, \$M	With Intertie, \$M	Benefit/Cost Ratio
Yes	0	208.9	182.7	1.14
	3	108.0	97.2	1.11
	6	69.1	64.1	1.08

As with the Northern Power wind turbine-only analysis, assuming a 50 percent higher 2018 fuel start price (\$6.16 in Noorvik and \$6.21 in Kiana) yields a concomitantly higher economic benefit, as one can see below.

Noorvik-Kiana intertie 50-year economic benefit, 50% higher fuel cost, with wind power

Wind Turbines	Discount Rate, %	Net Present Value		
		Without Intertie, \$M	With Intertie, \$M	Benefit/Cost Ratio
Yes	0	244.9	210.4	1.16
	3	125.2	110.4	1.13
	6	78.9	71.7	1.10

Intertie Variation – Wind Power at Hotham Peak

The three months of overlapping data collected at the Hotham Peak and the Quarry Road met tower sites, and other data sources or analyses such as AWS Truepower and earlier WAsP modeling, demonstrate a superior wind resource on Hotham Peak. But, developing this wind resource would be very capital intensive with a minimum 8 km (5.0 miles) of new road construction required and at least 7 km (4.4) miles of transmission extension to connect to the Noorvik-Kiana electrical intertie. The wind power production potential on Hotham Peak would be extraordinary, but so would the wintertime operational challenges of the maintaining the site, including possible frequent de-icing requirements and general access difficulties with keeping the road open and/or snowmachine travel. Another constraint is that the site is within the Selawik National Wildlife Refuge and construction of a permanent structure would present many permitting hurdles.

Despite the cost, operational challenges and permitting issues, development of wind power on Hotham Peak is achievable of course, but it would not be economically feasible without a larger power demand load to

serve. The obvious and only realistic option would be to connect the village of Selawik, located approximately 44 km (27.3 miles) southeast of the Quarry Road site and 37 km (23.0 miles) southeast of Hotham Peak. This option – a three-village intertie connection of Noorvik, Selawik, and Kiana – was analyzed in the August 2014 *Intertie Options for Selected AVEC Villages* report and was deemed economically viable. Not meaningfully discussed in that report, however, are the challenges of construction through Selawik National Wildlife Refuge, which although possible shouldn't be minimized with respect to time required for permitting and possible opposition by outside entities.

For these reasons, wind power development of Hotham Peak to serve only an intertied Noorvik-Kiana power system, which is the focus of this report, is not considered viable at the present time and hence focus remains on the Quarry Road site.

Wind-Diesel Hybrid Power System Basics

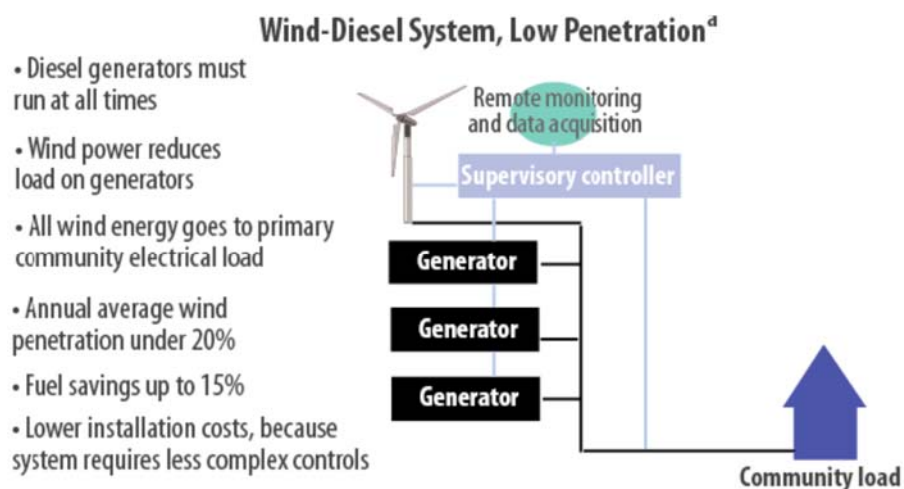
The State of Alaska is a world leader in wind-diesel hybrid power system design and operation with more than twenty operational systems and many more planned.

Wind-Diesel Design Options

Wind-diesel power systems are categorized based on their average penetration levels, defined as the proportion of wind-generated electricity compared to the total amount of electrical energy generated. Commonly used categories of wind-diesel penetration levels are low, medium, and high; occasionally very low is also defined as a category. Wind penetration level roughly correlates to the amount of diesel fuel displaced by wind power.

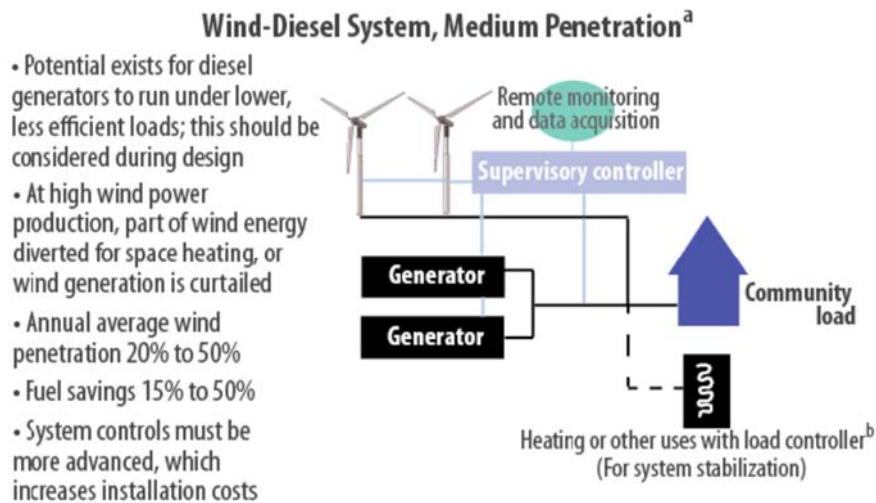
Low (and very low) Penetration Configuration

Low (and very low) penetration wind-diesel systems require the fewest modifications to the existing system. However, they tend to be less economical than higher penetration configurations due to the limited annual fuel savings compared to fixed project development costs, such as access roads and new distribution connections.



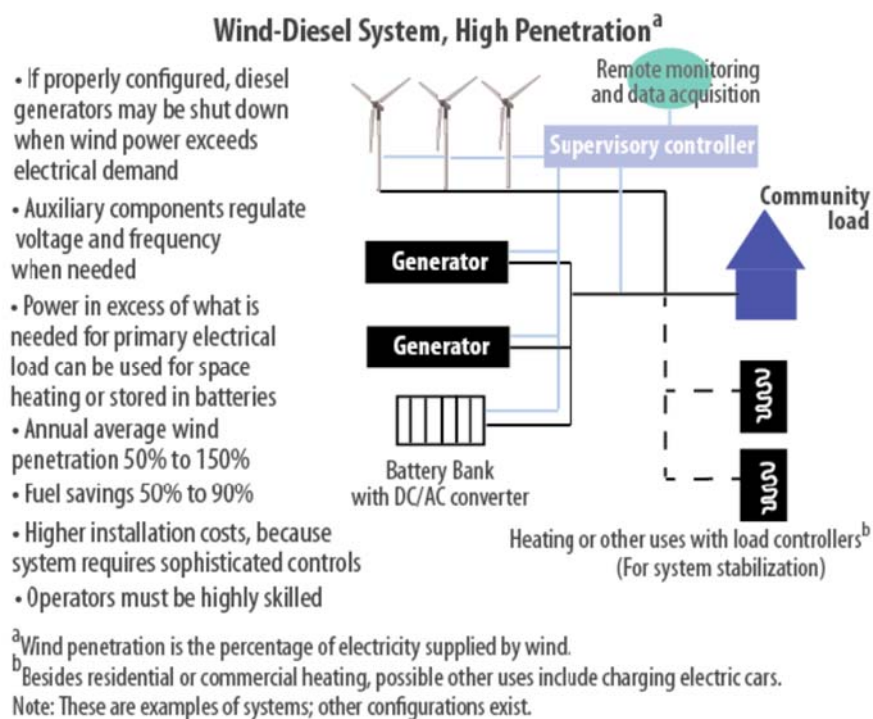
Medium Penetration Configuration

Medium penetration wind-diesel requires relatively sophisticated power quality control due to occasional circumstance of wind generation exceeding load demand and generally are with a full-time diesels-on requirement. Medium penetration is often chosen as a compromise between the minimal benefit of low penetration and the considerable complexity of high penetration, but experience has indicated that this may be misleading. Power quality can be difficult to maintain with typical medium penetration configuration design and upgrades necessary to improve power quality control edge enough toward high penetration that the greater economic benefits of high penetration wind are not captured due to insufficient wind turbine capacity.



High Penetration Configuration

High penetration configuration design typically enables diesels-off operation and uses a significant portion of the wind energy for thermal heating loads. The potential benefit of high penetration can be significant, but system complexity requires a significant investment in project commissioning, operator training, and strong management practices.



Average vs. Instantaneous Penetration

Wind-diesel penetration levels are summarized table below in a table developed by Alaska Energy Authority. Note that instantaneous penetration level is significantly more important with respect to system design than average penetration. One way to appreciate instantaneous penetration and its design implications is to consider the brakes of an automobile. Braking systems are designed for the maximum (or instantaneous) vehicle speed of, say, 200 km/h (124 mph), not the vehicle's typical average speed of 50 km/h (31 mph). If the brakes were designed for an average 50 km/h vehicle speed, one would be able to stop when driving at highway cruising speeds, let alone the maximum vehicle speed!

The annual contribution of wind energy, expressed as percentage of wind energy compared to load demand, is the average penetration level.

Categories of wind-diesel penetration levels

Penetration Category	Wind Penetration Level		Operating Characteristics and System Requirements
	Instantaneous	Average	
Very Low	<60%	<8%	<ul style="list-style-type: none"> • Diesel generator(s) runs full time • Wind power reduces net load on diesel • All wind energy serves primary load • No supervisory control system
Low	60 to 120%	8 to 20%	<ul style="list-style-type: none"> • Diesel generator(s) runs full time • At high wind power levels, secondary loads are dispatched to insure sufficient diesel loading, or wind generation is curtailed • Relatively simple control system

Penetration Category	Wind Penetration Level		Operating Characteristics and System Requirements
	Instantaneous	Average	
Medium	120 to 300%	20 to 50%	<ul style="list-style-type: none"> • Diesel generator(s) runs full time • At medium to high wind power levels, secondary loads are dispatched to insure sufficient diesel loading • At high wind power levels, complex secondary load control system is needed to ensure heat loads do not become saturated • Sophisticated control system
High (Diesels-off Capable)	300+%	50 to 150%	<ul style="list-style-type: none"> • At high wind power levels, diesel generator(s) may be shut down for diesels-off capability • Auxiliary components required to regulate voltage and frequency • Sophisticated control system

Penetration Configuration Considerations

In general, medium penetration is a good design compromise as it enables a relatively large amount of displaced fuel usage but requires only a moderate degree of system complexity. Medium penetration is the preferred system configuration of Alaska Village Electric Cooperative (AVEC), owner and operator of eleven wind-diesel systems statewide, including Noorvik and Kiana. AVEC's experience provides a useful guide for Northwest Arctic Borough and NANA Regional Corp. as they aid for borough communities.

It should be noted however that not everyone in the wind-diesel industry categorize wind penetration as does Alaska Energy Authority. Many collapse the penetration categories to just two: low and high. This simplification recognizes that system design is informed by the degree of instantaneous, not average, penetration. Additional nuances are diesels-off capability and inclusion of storage options. For village wind power, a project that can displace a significant amount of diesel fuel and provide real economic benefit to the community invariably *must be* high penetration by the low/high definition. With this in mind, limiting average penetration to a compromise level of 20 to 50 percent may make very little sense. With a design configuration capable of controlling 100 percent and higher instantaneous penetration, there is no particular reason to limit average penetration to a pre-determined percentage as with Alaska Energy Authority's definition of medium penetration.

System Components

The main components of a medium-to-high penetration wind-diesel system include:

- Wind turbine(s), plus tower and foundation
- Supervisory control system
- Secondary load (plus its controller)
- Deferrable load
- Interruptible load
- Energy Storage
- VAR compensator

Wind Turbine(s)

Village-scale wind turbines are generally considered to be 50 kW to 500 kW rated output capacity. This turbine class once dominated the worldwide wind power industry but has long been left behind in favor of much larger 1.5 MW plus capacity turbines. Conversely, many turbines are manufactured for home or farm application, but generally these are 10 kW capacity or less. Consequently, few new village size-class wind turbines are on the market, although a large supply of used and/or remanufactured turbines are available. The latter typically result from repowering older wind farms in the United States and Europe with new, larger wind turbines.

Supervisory Control System

Medium- and high-penetration wind-diesel systems require fast-acting real and reactive power management to compensate for rapid variation in village load and wind turbine power output. A wind-diesel system master controller, also called a supervisory controller, would be installed inside the Wainwright power plant or in a new module adjacent to it. The supervisory controller would select the optimum system configuration based on village load demand and available wind power.

Secondary Load

A secondary or “dump” load during periods of high wind is required for a wind-diesel hybrid power system to operate reliably and economically. The secondary load converts excess wind power into thermal power for use in space and water heating through the extremely rapid (sub-cycle) switching of heating elements, such as an electric boiler imbedded in the diesel generator jacket water heat recovery loop. A secondary load controller serves to stabilize system frequency by providing a fast responding load when gusting wind creates system instability.

An electric boiler is a common secondary load device used in wind-diesel power systems. An electric boiler (or boilers), coupled with a boiler grid interface control system, could be installed in Wainwright to absorb excess instantaneous energy (generated wind energy plus minimum diesel output exceeds electric load demand). The grid interface monitors and maintains the temperature of the electric hot water tank and establishes a power set point. The wind-diesel system master controller assigns the set point based on the amount of unused wind power available in the system. Frequency stabilization is another advantage that can be controlled with an electric boiler load. The boiler grid interface will automatically adjust the amount of power it is drawing to maintain system frequency within acceptable limits.

Deferrable Load

A deferrable load is electric load that must be met within some time period, but exact timing is not important. Loads are normally classified as deferrable because they have some storage associated with them. Water pumping is a common example - there is some flexibility as to when the pump actually operates, provided the water tank does not run dry. Other examples include ice making and battery charging. A deferrable load operates second in priority to the primary load and has priority over charging batteries, should the system employ batteries as a storage option.

Interruptible Load

Electric heating either in the form of electric space heaters or electric water boilers could be explored as a means of displacing stove oil with wind-generated electricity. It must be emphasized that electric heating is

only economically viable with excess electricity generated by a renewable energy source such as wind and not from diesel-generated power. It is typically assumed that 40 kWh of electric heat is equivalent to one gallon of heating fuel oil.

Storage Options

Electrical energy storage provides a means of storing wind generated power during periods of high winds and then releasing the power when the wind subsides. Energy storage has a similar function to a secondary load but the stored wind energy can be converted back to electric power for the grid at a later time. There is, naturally, a loss of efficiency with the conversion of power to and from storage.

Flywheel

A flywheel energy system provides short-term energy storage to smooth the short-term variability of wind power, and has the additional advantage of frequency regulation. The smallest capacity flywheel available from Powercorp (now ABB), however, is 500 kW capacity, hence it is most suitable for larger village power generation systems.

Battery

Battery storage is a generally well-proven technology and has been used in Alaskan power systems including Fairbanks (Golden Valley Electric Association), Wales and Kokhanok, but with mixed results in the smaller communities. Batteries are most appropriate for providing short to medium-term energy storage to allow a transition, or “bridge”, between the variable output of wind turbines and diesel generation. This “bridging” period is typically one to five minutes. Storage for long periods of time, such as hours or even days, is possible with batteries, but this requires much higher capacity and cost. In general, the disadvantages of batteries for utility-scale energy storage, even for small utility systems, are high capital and maintenance costs and limited lifetime. Of particular concern to rural Alaska communities is that batteries are heavy and expensive ship and most types contain hazardous substances that require special handling at the end of their service life with disposal in specially-equipped recycling facilities.

Grid-Bridging Energy System

An innovative solid state storage concept is the use of ultra-capacitors to provide short-term energy needs to smooth the variability of wind power and, as with a flywheel or battery, provide a transition or “bridge” between a stochastic renewable energy source and grid-following diesel generator. Alaska Village Electric Cooperative is championing this technology as a control solution for its wind-diesel power systems.

VAR Compensation

VAR (voltage-ampere reactive) compensation may be necessary, especially with high wind power input, as electrical loads both generate and absorb reactive power. Since the transmitted load often varies considerably from one hour to the next, the reactive power balance in a grid varies as well. This can result in unacceptable variations in voltage, including voltage depression or even voltage collapse (ref: ABB website).

Static VAR Compensation (SVC)

A Static VAR Compensator (SVC) is a device that can quickly and reliably control line voltages. An SVC will typically regulate and control the voltage to the required set point under normal steady state and contingency conditions and thereby provide dynamic, fast response reactive power following system contingencies (e.g. network short circuits, line and generator disconnections). In addition, an SVC can also

increase transfer capability, reduce losses, mitigate active power oscillations and prevent over voltages at loss of load (ref: ABB website).

STATCOM

Similar to SVC but faster, STATCOM continuously provides variable reactive power in response to voltage variations, supporting the stability of the grid. STATCOM operates according to voltage source converter principles, combining unique pulse width modulation with millisecond switching. STATCOM functions with a very limited need for harmonic filters, contributing to a small physical footprint. If required, switched or fixed air core reactors and capacitors can be used with the voltage source converter as additional reactive power elements to achieve any desired range (ref: ABB website).

Synchronous Condenser

A synchronous condenser, also referred to as a synchronous compensator, is a specialized synchronous-type electric motor-generator with an output shaft that spins freely. Its excitation field is controlled by a voltage regulator to either generate or absorb reactive power as needed to support grid voltage or to maintain the grid power factor at a specified level.

Wind-Diesel Philosophy

Installing wind turbines and creating a wind-diesel power system in an Alaskan village is a demanding challenge. At first glance, the benefits of wind power are manifest: the fuel is free and it is simply a manner of capturing it. The reality of course is more complicated. Wind turbines are complex machines and integrating them into the diesel power system of a small community is complicated. With wind-diesel, a trade-off exists between fuel savings and complexity. A system that is simple and inexpensive to install and operate will displace relatively little diesel fuel, while a wind-diesel system of considerable complexity and sophistication can achieve very significant fuel savings.

The ideal balance of fuel savings and complexity is not the same for every community and requires careful consideration. Not only do the wind resource, electric and thermal load profiles, and powerhouse suitability vary between villages, so does technical capacity and community willingness to accept the opportunities and challenges of wind power. A very good wind-diesel solution for one village may not work as well in another village, for reasons that go beyond design and configuration questions. Ultimately, the electric utility and village residents must consider their capacity, desire for change and growth, and long-term goals when deciding the best solution that meets their needs.

The purpose of this report is to discuss the viability of wind power in Noorvik and Kiana. As discussed, many options are possible, ranging from a very simple low penetration system to a highly complex, diesels-off configuration potentially capable of displacing 50 percent or more of fuel usage in the community. It is possible that Northwest Arctic Borough, NANA Regional Corporation, and Noorvik and Kiana residents ultimately will prefer a simple, low penetration wind power system, or alternatively a very complex high penetration system, but from past discussions and work it appears that a moderate approach to wind power in Noorvik and Kiana is preferable, at least initially.

With a moderately complex project design framework in mind, a configuration of relatively high wind turbine capacity with no electrical storage and no diesels-off capability was chosen. This provides sufficient wind

capacity to make a substantive impact on fuel usage but does not require an abrupt transition from low to high complexity. Although conceptually elegant, there is a trade-off to consider with this approach. Installing a large amount of wind power is expensive, but without electrical or thermal storage some of the benefits of this wind power capacity may not be used to best advantage.

The thermodynamics of energy creation and use dictates that wind power is more valuable when used to offset fuel used by diesel generators to generate electricity than fuel used in fuel oil boilers to serve thermal loads. More specifically, boilers convert fuel oil to hydronic heat at 85 to 95 percent thermal efficiency, but diesel generators convert fuel oil (diesel) to electrical energy at only 35 to 45 percent thermal efficiency, hence it is preferable to replace the least efficient generation method first. Excess system electricity must be shunted via a secondary load controller to the diesel generator heat recovery loop or simple radiation heaters to avoid curtailing wind turbines during periods of high wind and relatively light electrical load.

Although perhaps not readily apparent in the report, this compromise of wind capacity versus complexity is contained within the economic benefit-to-cost tables. This compromise, which is endemic to wind-diesel, results in high capital costs, but usage of the energy generated is imperfect from an efficiency point of view. The most efficient usage of wind energy from a technical point of view – offset of electrical power, may be too expensive from a cost-benefit perspective.

It is important not to focus strictly on benefit-to-cost ratio of a particular configuration design or particular turbine option, but also consider a wider view of the proposed wind project for Noorvik and Kiana. Installing approximately wind power has considerable short-term benefit with reduction of diesel fuel usage, but more importantly it would provide a platform of sustainable renewable energy growth in Wainwright for many years to come. This could include enhancements such as additional thermal load offset, battery storage and/or use of a flywheel to enable diesels-off capability, creation of deferred heat loads such as water heating, and installation of distributed electrical home heat units (Steffis heaters or similar) controlled by smart metering. The latter, presently operational to a limited extent in the villages of Kongiganak, Kwigillingok, Tuntutuliak, has enormous potential in rural Alaska to not only reduce the very high fuel oil expenses borne by village residents, but also to improve the efficiency and cost benefit of installed and future wind power projects. These opportunities and benefits are tangible and achievable, but their cost benefit was not modeled in this report.

Lastly, it must be acknowledged that a wind power project in Noorvik and Kiana (if intertied) will provide benefits that are not easily captured by economic modeling. These are the *externalities* of economics that are widely recognized as valuable, but often not included or discounted because they might be considered as soft values compared to capital cost, fuel quantity displaced, etc. These include ideals such as long-term sustainability of the village, independence from foreign-sourced fuel, reduction of one's carbon footprint, and opportunities for education and training of local residents. Beyond these somewhat practical considerations, there is the simple moral argument that renewable energy is the right thing to do.

Recommendations

Besides the proposed electrical transmission intertie itself, a number of wind power site and turbine options are presented in this report. Assuming the capital cost estimate is correct, clearly it is beneficial to construct an intertie to connect Noorvik and Kiana. Technical hurdles may be encountered, however, immediately

south of Kiana with crossing the Kobuk River, but assuming that challenge can be overcome, construction of an intertie stands on its own merits. But, because the intertie route must pass the location of Noorvik's Quarry Road prospective wind power site, development of wind power at this location provides renewable energy benefits to both communities and hence most definitely is recommended.

A key question though is which wind turbine option to recommend: the multi-turbine Northern Power Systems 100 or the single turbine EWT DW900. The EWT appears to be most beneficial economically but operationally a single wind turbine at relatively high power penetration is trickier with respect to operating (or spinning reserve) than multiple wind turbines. AVEC, the electric utility of Noorvik and Kiana, has for the past ten plus years favored the Northern Power turbine in multi-turbine configurations, but has recently selected the EWT in a single turbine approach in two of its intertie-paired communities. These systems are not yet constructed, however, and hence there is no operational history to consider.

It should be noted that a high penetration, single wind turbine configuration in an isolated grid application in Alaska has not yet been constructed and operated and possibly there will be unforeseen challenges to address. Likely there will be sufficient time to observe and learn from AVEC's experience with single turbine EWT systems before choosing a wind turbine for Noorvik and Kiana. If AVEC's new projects go well, then a single-turbine EWT configuration would be the preferred choice for Noorvik and Kiana, but until then the conservative and recommended approach is a multi-turbine configuration with Northern Power Systems 100 wind turbines.

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