Wind-Diesel Hybrid Options for Remote Villages in Alaska

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ABSTRACT

Nearly 200 villages in Alaska lie beyond the reach of power lines and roadways. These communities receive their electricity from local diesel power plants and receive their fuel and supplies by barge or airplane. The delivery of diesel fuel to these remote villages is costly and subject to favorable environmental conditions. The use of diesel power plants also has environmental costs, including the risk of spills during transport or storage of the fuel and the emission of greenhouse gases, carbon dioxide, and particulates.

To address these issues, Alaska energy representatives are looking to renewable energy technologies to reduce the costs of power production in rural areas, the dependence on imported fuels, and exposure to fuel price fluctuations. One option under strong consideration is the use of renewable energy technologies. The National Renewable Energy Lab (NREL), in collaboration with the Alaska Village Electric Cooperative (AVEC) and the Alaska Energy Authority (AEA), is undergoing an analysis of village electric usage patterns, wind energy resource potential, and wind-diesel hybrid power options for remote communities in Alaska. This report describes the methods utilized and results completed to date as well as areas for further investigation.

1. BACKGROUND

Most of Alaska's electricity is produced by the use of fossil fuels, as shown in Figure 1 (U.S. DOE EERE 2003). Existing renewable energy facilities include 2 biomass, 1 geothermal, 52 hydroelectric, 3 photovoltaic and 4 wind power plants, making up 408 MW out of Alaska's 2,018 MW of installed capacity.

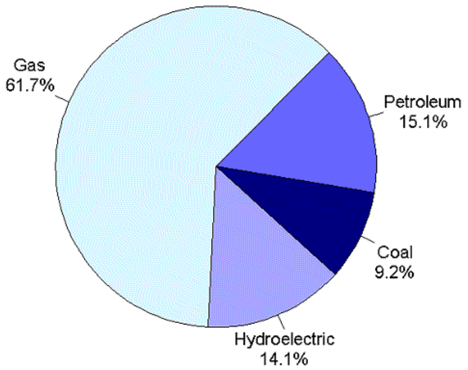


Fig. 1: Alaska Electricity Generation by Source, 1999

More than 118 independent utilities provide electricity to an estimated 620,000 people in Alaska, covering a geographically, economically, and culturally diverse range of communities (AEA website). Due to the rugged terrain and lack of a roadway system, supplying rural Alaskan communities with electricity is a challenge. These villages lie beyond the reach of the power grids serving the major urban areas. Instead, many rural villages are powered by diesel mini-grids of up to 3 MW in capacity.

The delivery of fuel is limited to 1-4 shipments by barge per year and is dependent upon favorable environmental conditions. In 2002, the average delivered diesel fuel price ranged from $1.02 to $2.88 per gallon (AVEC). A 9 to 13 month supply of fuel must be stored on site in tank farms, which may be subject to leaks and spills. Many of the plant complexes and storage tanks are aging and in need of major upgrades and expansion as energy needs increase.

The average residential electric rate for AVEC customers is 39.9 cents per kWh. The state offers a

Power Cost Equalization (PCE) subsidy for rural communities, which averages 17.5 cents per kWh for the first 500 kWh per month. The effective average residential rate is 22.4 cents per kWh. The goal of the PCE is to equalize the cost of electricity statewide; however, even with the PCE subsidy, rural electric costs are often two or three times higher than in urban areas (AEA 2003).

As the least-cost small-scale renewable energy technology currently available, wind energy is a serious option in reducing the use of diesel and the exposure to fuel price volatility. Demonstration wind-diesel hybrid systems are currently operating in the Alaskan villages of Wales, Kotzebue, Selawik, and St. Paul. Although much experience has been gained from these systems, the wind-diesel industry in Alaska is still fairly new (Drouilhet 2001).

2. PURPOSE

In order to determine the economic and technical feasibility of a wind energy system, computer modeling of the different options must be done. Two primary pieces of information are essential in accurately modeling the expected performance of wind-diesel systems: village electric use patterns, and local wind resource. For many Alaskan villages, this information is not readily available. The purpose of this report is to present methods used to obtain both wind resource and electric load data in villages. A case study will be given to illustrate how this information is used in modeling hybrid wind-diesel options for remote villages.

3. ANALYSIS OF VILLAGE ELECTRIC USE

Before designing a village electric power system, the current and anticipated long-term electric loads must be defined. The definition of the loads includes average and peak electric demand for different seasons and the pattern of electric use throughout the day. Each of these must be understood if the analysis is going to correctly model power system performance.

In many cases, detailed village load information is not readily available; therefore, a method for estimating these loads is needed. Such a method is described below. Data for most of this analysis was obtained by reviewing the metered electrical usage of customers in villages serviced by AVEC.

To begin the load analysis we have broken down the electric use for a number of communities into its primary components. Figure 2 shows the approximate breakdown of electric use of the villages in the AVEC service area.

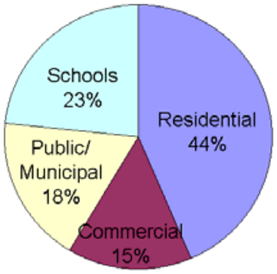


Fig. 2: Village Energy Use by Sector

The residential sector is the largest consumer of electricity, followed by the school and public sectors.

The residential load is driven by the number of homes in a community and their socio-economic condition. Electric loads that can be found in a typical home include lighting, a color TV, electric stove, refrigerator, forced air fan, and a clock radio. Homes with piped water have electric heat trace to prevent freezing. More modern homes will have a computer, washer and dryer, satellite dish, microwave, and additional lights and television sets. Residents with a higher household income will use as much as 1,000 kWh a month or more. However, the majority of village homes use 200 to 400 kWh per month. Most homes use kerosene or fuel oil for heating.

Facilities in the public/ municipal sector include a water treatment plant, post office, airport, and city offices. The commercial sector makes up about 15% of village electric consumption and typically includes a general store, hardware store, and a number of restaurants.

Typically, the two primary non-residential customers in a village are the school and the public water treatment facility, each of which will be described in more detail in the following section. Throughout this analysis we have elected to normalize the consumption by the population within each community. This allows easy comparisons between communities of various sizes and also acts as a reasonable baseline for community level services and energy use.

3.1 Public Water Systems

Public water systems include any facilities that supply water to a community and that dispose of wastewater. There are many factors influencing the electric consumption of a public water system, including the size of the population served, the level of treatment of the water and wastewater, the method of distribution, and the climate. However, village public water systems in Alaska can generally be split into two levels.

Level I public water systems provide piped water and sewer to all city buildings and most homes. These systems usually have aboveground water mains, which need to be protected from freezing. Options include heating the water mains with electric heat tape, using a boiler to heat a glycol loop that runs through the water distribution system, or continuously pumping the water through a closed-loop system.

In Level II public water systems, water is pumped from a well or surface source, treated, and stored in an insulated tank. The water is supplied to a central washeteria where residents can collect water, bathe, and do laundry. Electric loads at these water treatment/washeteria facilities include pumps, washing machines and dryers, lights, and sometimes an electric sauna. These basic systems do not treat wastewater; instead, each resident collects their wastewater in five-gallon “honey buckets” and hauls them to a sewage lagoon to be dumped. Almost half of Alaska’s 200 native villages do not have running water or flush toilets in their homes (Rural Alaska Sanitation Coalition).

Figure 3 shows the average monthly electric consumption of the basic Level II and the piped Level I water systems, based on a survey of utility bills from 10 villages.

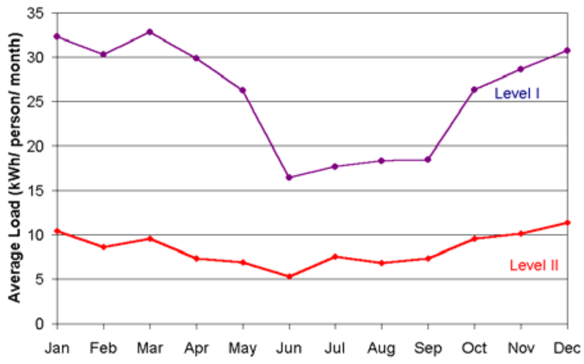


Fig. 3: Average Load Profile of Public Water System

The electric consumption of public water systems can vary drastically from village to village. Most villages begin with a basic Level II system and gradually move towards a Level I system as funding is available.

3.2 Schools

As the single largest electric user in a village, the schools have a great impact on the total village electric load profile. Villages tend to have one school building, which serves students in pre-school or kindergarten through 12th grade. Major electric loads within the school include air handling units, lighting, water pumps for a hot water radiator system, and kitchen appliances. For safety reasons, ranges and ovens in the cafeteria may use electricity rather than propane. Space heat is usually provided by oil-fired furnaces or by heat recovered from the power plant cooling system. The building, particularly the gym and library, is typically used in the evenings and weekends for after school programs and community meetings. The use of the building drops drastically in the summer.

The electric consumption of eight village schools from 1998 through June 2003 was observed to have similar seasonal load patterns. The average load profile is shown in Figure 4.

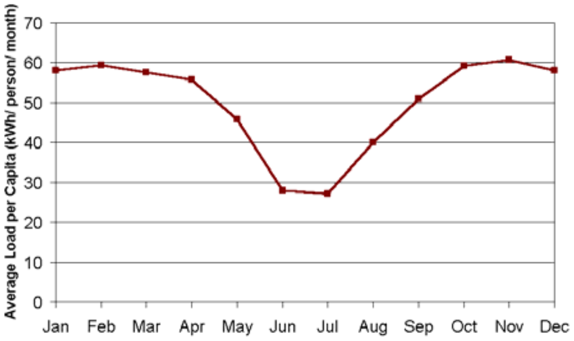


Fig. 4: Average Load Profile of K-12 Schools

3.3 Total Village Load Profile

Similar seasonal load profiles are created for the other primary loads typically found in a village, including a health clinic, communication facilities, governmental offices, and commercial buildings. Using this data we can build upon existing knowledge of expansion plans for different communities or estimate the energy usage of non-electrified communities by simply adding the different expected loads in a building block approach. An example of using such an approach is shown in Figure 5, for Selawik, Alaska.

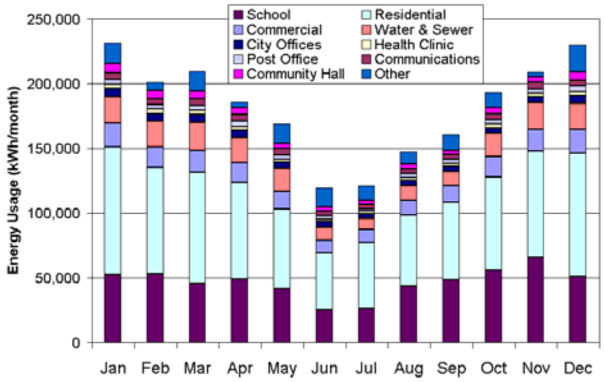


Fig. 5: Components of Village Electric Use

The "Other" block represents the difference between the building-block estimation method and the actual measured seasonal profile for Selawik. The average error between the estimated load and the actual load is 7%.

3.4 Daily Load Profiles

Daily load profiles for individual consumers of electricity in a village are not available at this time. What follows, however, is an analysis of the total village load profiles for six different villages where we were able to obtain high quality load data: Selawik, Chevak, Kiana, Gambell, Scammon Bay, and New Stuyahok. Each of these communities represent a different size and different levels of community services.

As one would expect, the daily load profile for the community depends on the type of buildings and services in a community and on the season. Figure 6 compares summer and winter daily load profiles for the six communities mentioned, normalized by village population.

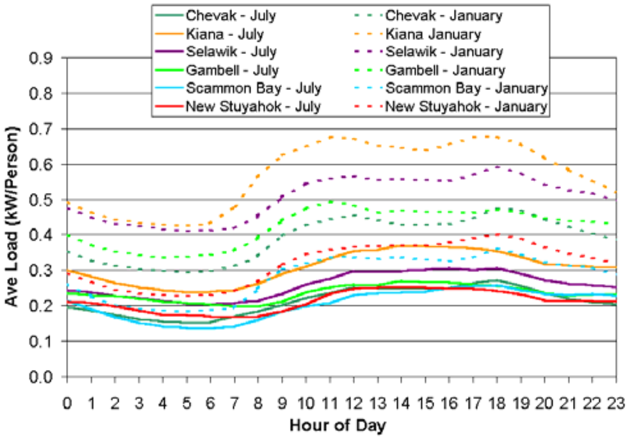


Fig. 6: Winter and Summer Daily Load Profiles

While the magnitude of the load fluctuates from summer to winter, the shape of the profile changes little. It is also important to note that the shape of the profile is similar between villages of different sizes. The magnitude is different, particularly in the winter, which can be attributed to the different types of services available in the community, such as the level of public water system.

This loads analysis allows for predictions to be made on the expected load growth of a village. For example, if the construction of new facilities is planned in the community or if upgrades will be made to the water treatment plant, estimates can be made based on the analysis of the individual facilities described here.

4. ALASKA WIND RESOURCE

Of the 175 remote villages in Alaska, it is estimated that 90 are located in potentially windy regions (Meiners 2002). The wind resource map in Figure 7 shows that wind speeds of up to Class 7 occur along the Alaskan coastal and islands areas and over the mountainous areas in the interior (U.S. DOE RRDC).

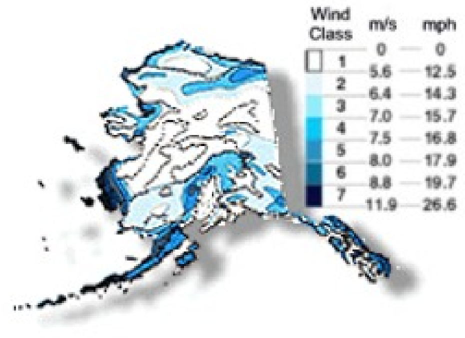


Figure 7. Wind Resource Map of Alaska

More detailed information on the wind resource at each village is needed to accurately evaluate and design a wind-diesel system. To address this need, AVEC, the Alaska Energy Authority, True Wind Solutions, and the National Renewable Energy Laboratory are developing a high-resolution wind resource map, and a number of wind resource assessment programs are being implemented in various rural communities.

Until this data is available, hourly wind resource measurements from local airports is used; however, the data recovery rate from these sites is often less than 90%.

5. WIND-DIESEL HYBRID SYSTEMS

The most promising application of renewable energy in Alaska is adding wind turbines to diesel power plants that are being upgraded to make a hybrid wind-diesel system. The wind turbines are connected directly to the grid and operate in parallel with the diesel generators, adding wind-generated electricity to the grid when available.

Various levels (penetrations) of wind energy can be included in the system. In low penetration systems, the wind turbine(s) are simply an additional generation source, requiring a trivial amount of controls. In medium-penetration systems, the average wind turbine output is up to 50% of the average electric load, allowing some diesel generators to be shut off or allowing smaller diesels to be used. Additional controls are required to ensure an adequate power balance and to maintain system voltage and frequency. High-penetration systems allow all the diesels to be shut off for long periods of time, but require more sophisticated controls and system integration (Baring-Gould 2003).

A variety of system configurations are possible, which include both diesel generators and wind turbines. The primary performance indicator by which the design options will be ranked is the amount of diesel fuel savings of the retrofitted system relative to the existing system. Other indicators include the amount of wind-generated electricity relative to the total village load (wind penetration) and the amount of excess energy generated that could provide heat. It should be noted, however, that different power system configurations require the installation of different amounts of system and control equipment. The resulting comparison of performance indicators, such as fuel savings, must be held against the cost to achieve that savings.

5.1 Wind Turbines

Cold weather climates, the lack of developed infrastructure, and the general small size of remote villages impose significant restrictions on which wind turbines may be used. Turbine design considerations include the potential icing of sensors and blades, increased fatigue on components, and changes in material properties at lower temperatures (particularly with the gearbox oil and rubber seals). The installation and maintenance of wind turbines is also affected by extreme weather conditions. Deep snowfall can limit access to wind turbines, and sub-zero temperatures create additional safety issues. The physical size of the turbine components is restricted to their ability to fit on a plane for shipment and the limited installation infrastructure in remote areas.

Only a few manufacturers of mid-sized wind turbines have a presence in the U.S. and Canada. The modern wind turbines currently installed in Alaska include the 65kW Atlantic Orient AOC15/50, the 100kW Northern Power NW100/19, and the 225 kW Vestas V27. This analysis focuses on the use of the first two turbines as the Vestas is not currently in commercial production.

All turbine power curves were adjusted to account for the higher air densities in cold climates. The annual average temperature of –4 ºC leads to an air density of 1.31 kg/m3. Therefore, a power curve scaling factor of 1.069 was used.

5.2 Storage

An additional design consideration for hybrid systems is the use of energy storage device. The amount of storage influences the system's ability to cover short-term fluctuations in wind energy and/or the village load. The addition of energy storage into a high-penetration wind-diesel system can increase the fuel savings and reduce the diesel generator operating hours and number of starts. These factors affect the wear on the diesel machines and resulting maintenance and overhaul costs. However, the storage equipment is expensive and difficult to ship, install and maintain, and their useful lifetime is generally limited to 5-15 years.

In low penetration systems, storage is not required since the wind does not provide enough power to allow the diesels to be shut off. Storage is also not required in medium and high-penetration systems if an adequate dump load and synchronous condenser are provided to maintain voltage and frequency stability. This preliminary analysis investigates the potential of low to high penetration systems with no storage. The costs and benefits of adding battery storage systems will be considered at a later time.

In a system without energy storage, a dispatchable energy source (the diesel engine in this case) must be used to cover the difference between the power required by the community (the village load) and power being supplied by the wind turbine. This difference is usually called the instantaneous net load. The net load fluctuates due to changes in the village load and changes in power from the wind turbine due to changes in the wind speed. In order to cover any anticipated increases in the net load, an operating reserve must be maintained. In this analysis a reserve equal to 20% of the wind power output was used.

The no-storage system can include a dump load to absorb any excess electricity generated and to maintain system frequency. Systems may also include active load control to shut off non-critical loads in time of power shortage. At least one diesel is always in operation to provide reactive power and maintain system voltage.

5.3 Optional Loads

An additional benefit of a high-penetration wind-diesel system is that the excess wind energy generated could supply power to an optional load. Alaska's climate supports this concept of higher-penetration systems because any excess energy can be used year-round for heating. Currently, some villages use heat recovered from the diesel power plant to provide space heating or hot water. This recovered heat use must be considered in the installation of any alternative generation source that may reduce the use of the diesel engine.

6. CASE STUDY: CHEVAK

Chevak is a village in the Yukon-Kuskokwim Delta on the north bank of the Niglikfak River. According to the 2000 census, 96% of the 850 residents are Alaska Native or part Native. The climate is affected by heavy winds and rain from the Bering Sea. Temperatures can range from –25º to 79ºF, and snowfall averages 60 inches per year.

Employment in Chevak is seasonal, with the majority of work provided by construction projects, commercial fishing, and firefighting in the summer. Handicrafts and subsistence activities, such as harvesting salmon, seal, walrus, clams, and waterfowl provide supplemental income. According to the 2000 census, the unemployment rate is 15% and the median household income is $26,875 (DCED 2003).

Transportation services include a gravel airstrip, float plane landing on the Chevak Lake or Ninglikfak River, and a barge landing. Boats, all-terrain vehicles, and snowmobiles are the main forms of local transportation.

Chevak is a rapidly growing community. The village began construction of a piped water and sewer system in 1995, and a majority of the homes are currently connected. Unserved residents haul water from a central source or have rain catchment systems. Other completed projects include a new landfill, washeteria upgrades, a new watering point, water treatment plant, water storage tank, sewage lagoon, a vacuum sewer plant, and a new K-12 school.

6.1 Electricity Use in Chevak

Information on village energy consumption in Chevak was provided by AVEC. A summary of the electric and diesel fuel consumption of 2002 is shown in Table 1.

Table 1. Summary of 2002 Energy Use in Chevak

Total Yearly Electric Use	2,173,400 kWh
Average Load	249 kW
Peak Load	501 kW
Fuel Consumption	160,230
Delivered cost of Fuel	$1.18/ gal
Cost of Generation	$0.087/ kWh

Construction has been unusually high in recent years. The village load grew 9% between 2000 and 2001 and 17% between 2001 and 2002. Figure 8 illustrates this growth.

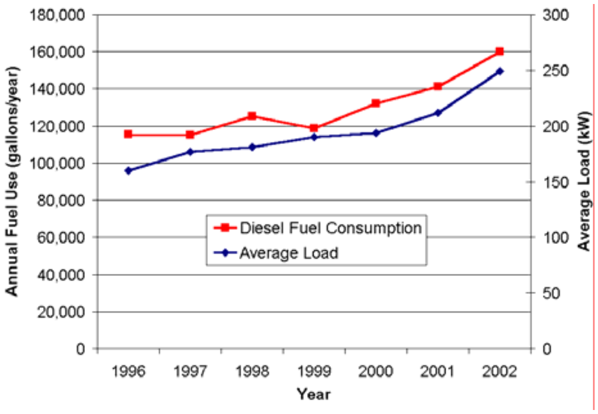


Fig. 8: Increase in Energy Use in Chevak

The recent load growth in Chevak is primarily due to the construction of a new school and the connection of nearly all homes to the electric grid and piped water system.

The seasonal village load profile in Figure 9 indicates a higher consumption of electricity in the winter than in the summer.

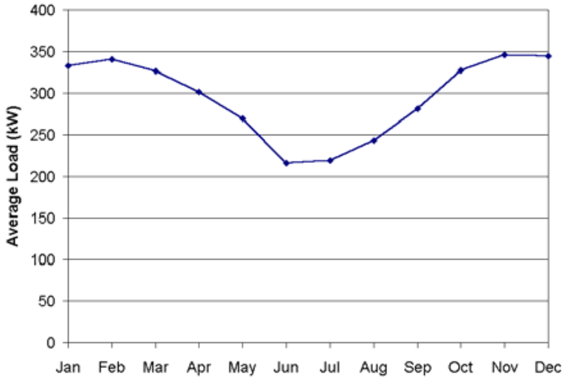


Fig. 9: Seasonal Load Profile for Chevak, AK

AVEC monitored the instantaneous electric production from the Chevak power station once every 15-minutes from 1996 to May 2003. Due to computer malfunction, most of 2002 data is missing. Therefore, this analysis uses the measured January

2003 – May 2003 data, plus the June 2001 - December 2001 data scaled up to meet the 2003 monthly kWh production. These 15-minute values were then averaged to create hourly values.

The diurnal load profile for an average day in each month is shown in Figure 10. These profiles were created by averaging each hour of each day of the month.

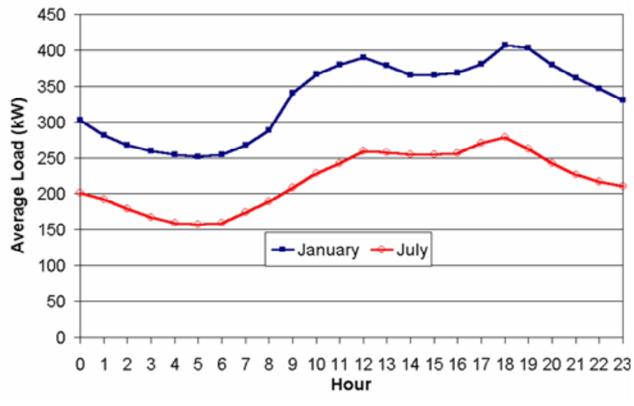


Fig. 10: Diurnal Load Profiles in Chevak

The winter load profiles show a sharp increase in the village load from 7:00 AM to a peak around 12:00 PM. The load dips slightly in mid-afternoon and peaks again in the early evening around 6:00 PM. The summer profile follows the same pattern but is less pronounced.

For modeling purposes, the expected village load in 2009 will be used to evaluate the performance of potential a hybrid power system. Although Chevak has seen rapid growth in electric consumption in recent years, it is expected that this growth will level out as the upgrade of major public facilities is nearing completion. Therefore, the 2003 hourly data obtained from AVEC is scaled up by a factor of 1.19 to account for a standard 3% growth rate per year. The modified values for 2009 are shown in Table 2.

Table 2. Expected Energy Requirements in 2009

Total Yearly Electric Use	3,081,000 kWh
Average Load	352 kW
Peak Load	610 kW
Fuel Consumption	232,400 gal/yr
Fuel Consumption	879,600 liters/yr

6.2 Existing Power Station

The Chevak power station includes three diesel generators totaling 1163 kW of rated capacity:

1) 499 kW Cummins KTA19G4
2) 350 kW Caterpillar 3412
3) 314 kW Detroit Diesel Series 60

The power system is manually controlled. The diesels are equipped with heat exchangers to provide space heating to the plant facilities. Useable diesel storage capacity is 136,700 gallons. Chevak usually receives 4 or 5 shipments of fuel per year.

The actual measured fuel curves for the diesel generators were obtained from AVEC. For the purposes of modeling, the minimum allowed power is specified at 40% of rated power.

If the power plant were to be redesigned incorporating wind power, the diesel plant would also be upgraded at the same time, likely to incorporate new diesel engines optimized to operate with the wind turbines.

6.3 Wind Resource

Detailed wind speed information for Chevak is not available at this time. Therefore, the wind speed data from the Hooper Bay village airport, located 15 miles to the west, is used. Since both villages are located along the shores of the Hooper Bay and are surrounded by flat terrain, it is reasonable to assume that the wind resource is similar between the two villages. However, a sensitivity analysis has been conducted to account for the uncertainty of this wind resource.

Average hourly wind speeds from January 1999 through December 1999 were obtained from the Hooper Bay weather station. The data recovery rate was 88%. Any gaps in the data due to equipment or data recording failure were filled using the Hybrid2 Gapfiller program. The gapfilled data set is shown in Figure 11.

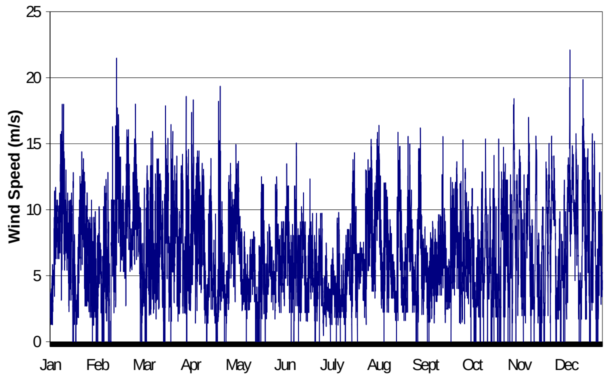


Fig. 11: Hourly Wind Speeds at Hooper Bay Airport

Since only one year of hourly data was available, the 1999 values were scaled to meet the long-term (1994-2002) average monthly wind speeds at the same location.

The seasonal and diurnal wind speed profiles are shown in Figures 12 and 13, respectively.

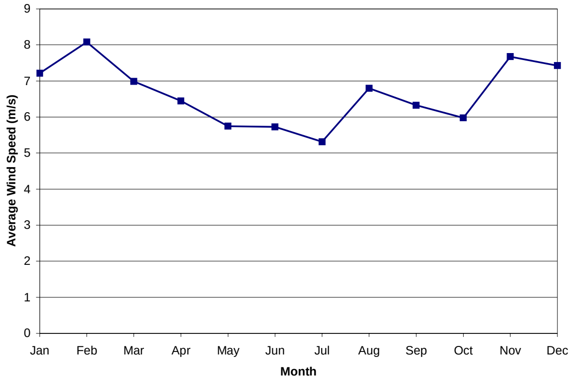


Fig. 12: Seasonal Wind Speed Profile for Hooper Bay

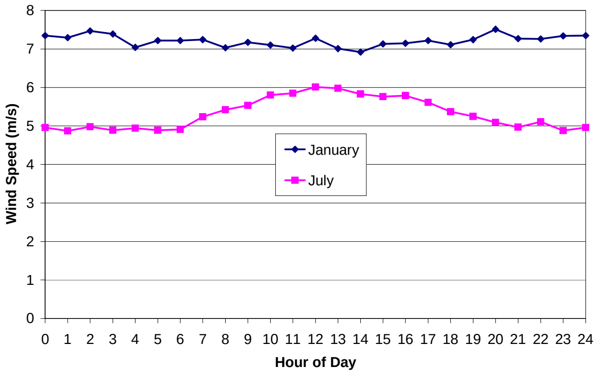


Fig. 13: Diurnal Wind Speed Profile for Hooper Bay

The annual average wind speed for the year is 6.65 m/s at a 10-meter height. The maximum wind speed recorded is 22.1 m/s.

The wind rose in Figure 14 indicates that the prevailing wind direction is from the north and east quadrants.

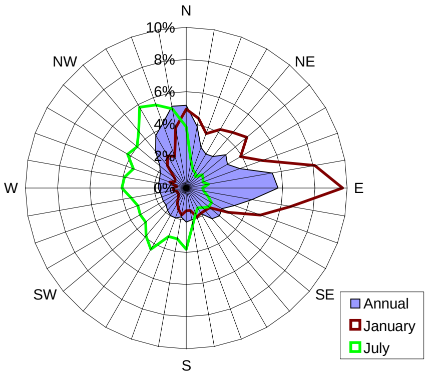


Fig. 14: Wind Frequency Rose for Hooper Bay

Since the standard deviation of the hourly wind data was not recorded, a constant variability of 0.15 is assumed for modeling purposes. In order to calculate the wind speed at hub height, the standard power law exponent of 0.143 was used.

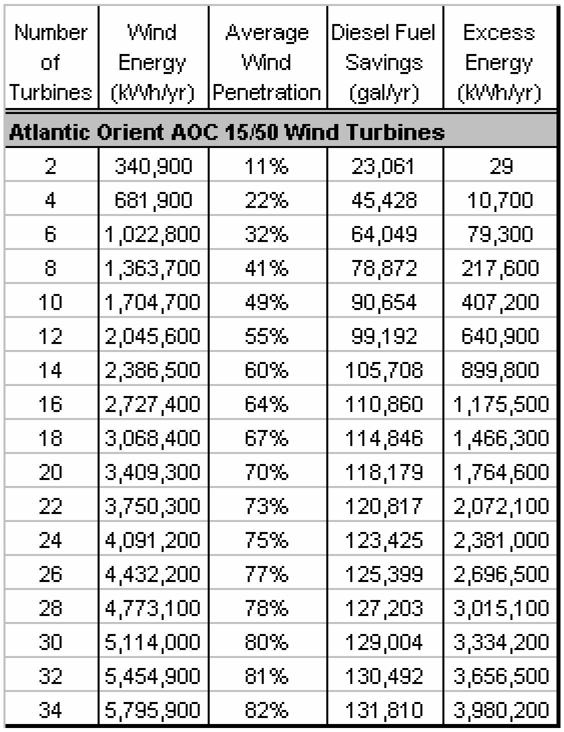
6.4 Expected Performance of Hybrid System

The primary performance indicator by which the options will be ranked is the amount of diesel fuel savings of the wind-diesel system relative to the existing system. To compare the design options of hybrid power systems, the computer simulation model HOMER, developed by the National Renewable Energy Lab, was used (NREL 2003). The use of the HOMER software allows the temporal association to determine how much of the expected energy production of the wind turbines can be used by the power system on any given hour. The hourly village load data and hourly wind speed data were imported into the simulation program to compare the output of two different models of wind turbines with a hub height of 25 meters. Up to 35 of each type of wind turbine was modeled.

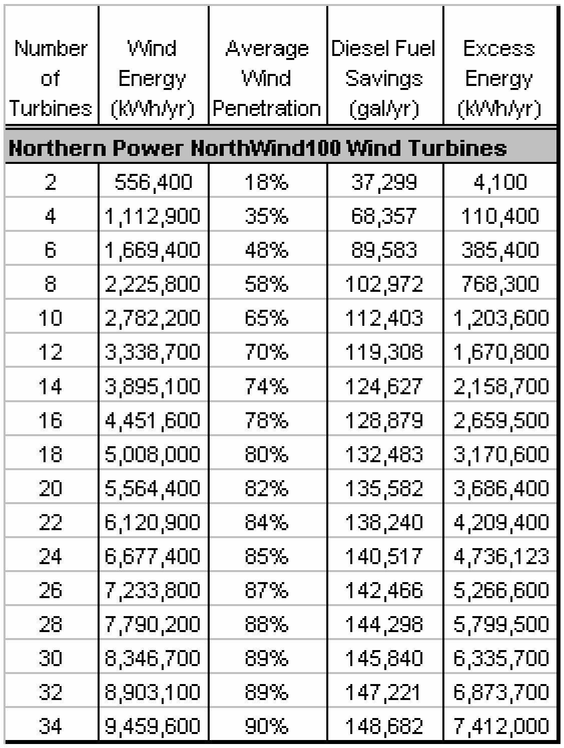
Based only on the wind speed at the site, one AOC 15/50 would generate approximately 170 MWh per year at an average annual wind speed of 6.6 m/s and 216 MWh at wind speed of 7.5 m/s. One Northern Power NW100 machine will generate about 277 MWh per year with an annual average wind speed of 6.6 m/s and 339 MWh at 7.5 m/s.

Further results are summarized below.

Table 3. Expected Performance of Hybrid System



Number of Turbines	Wind Energy (kWh/yr)	Average Wind Penetration	Diesel Fuel Savings (gal/yr)	Excess Energy (kWh/yr)
Atlantic Orient AOC 15/50 Wind Turbines				
2	340,900	11%	23,061	29
4	681,900	22%	45,428	10,700
6	1,022,800	32%	64,049	79,300
8	1,363,700	41%	78,872	217,600
10	1,704,700	49%	90,654	407,200
12	2,045,600	55%	99,192	640,900
14	2,386,500	60%	105,708	899,800
16	2,727,400	64%	110,860	1,175,500
18	3,068,400	67%	114,846	1,466,300
20	3,409,300	70%	118,179	1,764,600
22	3,750,300	73%	120,817	2,072,100
24	4,091,200	75%	123,425	2,381,000
26	4,432,200	77%	125,399	2,696,500
28	4,773,100	78%	127,203	3,015,100
30	5,114,000	80%	129,004	3,334,200
32	5,454,900	81%	130,492	3,656,500
34	5,795,900	82%	131,810	3,980,200



Number of Turbines	Wind Energy (kWh/yr)	Average Wind Penetration	Diesel Fuel Savings (gal/yr)	Excess Energy (kWh/yr)
Northern Power NorthWind100 Wind Turbines				
2	556,400	18%	37,299	4,100
4	1,112,900	35%	68,357	110,400
6	1,669,400	48%	89,583	385,400
8	2,225,800	58%	102,972	768,300
10	2,782,200	65%	112,403	1,203,600
12	3,338,700	70%	119,308	1,670,800
14	3,895,100	74%	124,627	2,158,700
16	4,451,600	78%	128,879	2,659,500
18	5,008,000	80%	132,483	3,170,600
20	5,564,400	82%	135,582	3,686,400
22	6,120,900	84%	138,240	4,209,400
24	6,677,400	85%	140,517	4,736,123
26	7,233,800	87%	142,466	5,266,600
28	7,790,200	88%	144,298	5,799,500
30	8,346,700	89%	145,840	6,335,700
32	8,903,100	89%	147,221	6,873,700
34	9,459,600	90%	148,682	7,412,000

Note: Analysis based on a wind speed of 6.64 m/s at the turbine hub height. Fuel savings based on a diesel-only system consumption of 227,300 gallons per year.

Figures 15 and 16 graphically illustrate the fuel savings.

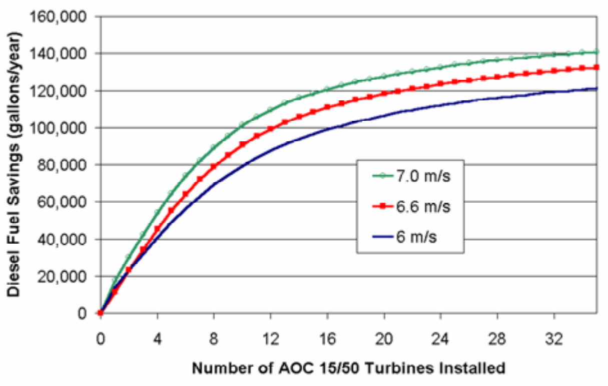


Fig. 15: Fuel Savings Using 65 kW Wind Turbines

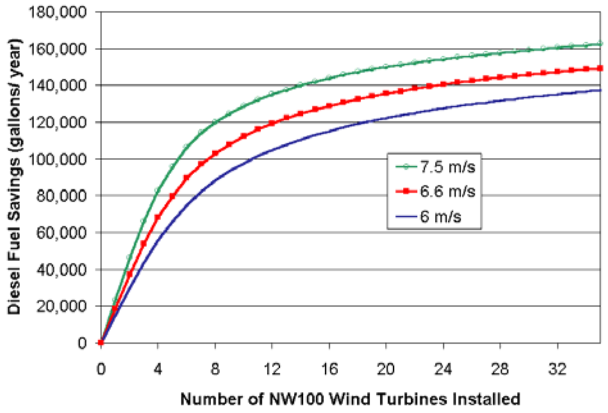


Fig. 16: Fuel Savings Using 100kW Wind Turbines

The figures show that increasing the number of wind turbines installed will increase the diesel fuel savings. However, the rate of fuel savings will decrease after a certain number of wind turbines are installed due to the mismatch between the wind resource and the load. Electricity generated by additional wind turbines may at times exceed what the village load requires. In some cases, a clear inflection point can be seen in the curve, indicating a local economic installation optimum.

6.5 Heating Requirements

Excess energy generated by the wind turbines could be used to provide heat to the village school, health clinic, or water treatment facility. Currently, heat is recovered from the diesel generators to provide hot water to the school. The heating loads of this building has not yet been quantified. The Chevak water plant, located 2 blocks from the power plant, currently uses an oil-fired furnace to provide hot water. According to plant personnel, the facility consumes 5,000 gallons of #1 fuel oil each month in the winter and 2,000 gallons per month during the summer. This translates to approximately 120 MWh and 50 MWH per month, respectively, in electrical heating needs. The fuel cost is about $2.40 per gallon, excluding shipping costs.

A wind system dump load could be incorporated into the existing heat recovery system for the school. The water treatment plant could also be added to the system to ensure that the year-round heating requirements are large enough to absorb any excess energy from the wind turbines. The exact configuration and location of the dump load is not specified in this report, but the amount of excess energy resulting from each system design will be noted. Figure 17 shows the amount of excess wind energy that would be available to supply this heating load each month if various numbers of 65kW wind turbines were installed in Chevak.

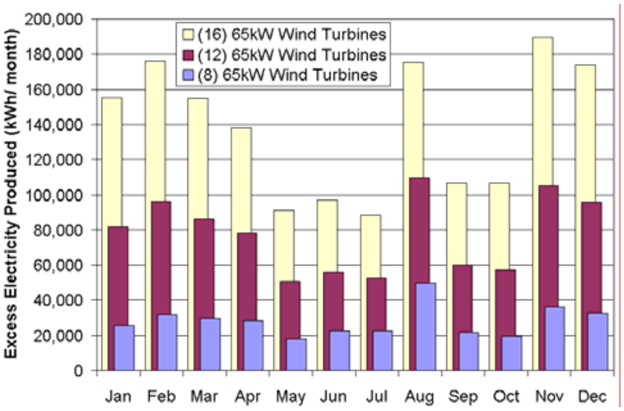


Fig. 17: Excess Electricity Produced in Chevak

7. ECONOMICS

The installation or upgrade of any power system in Alaska is often dependent on government funding sources and the availability of low-interest loans. State and federal funding, as well as funding from native or private corporations is available for projects in Alaska.

Due to the unique conditions of Alaska, particular costs are incurred during the installation of a wind energy system. For example, the wind turbine foundations are designed to have minimal impact on the frozen tundra, and often the installation must take place during the winter to ensure that the frozen ground will support the weight of the cranes, pile drivers, and fork lifts. Based on manufacturer quotes and data from previous installations, Table 4 summarizes these costs.

Table 4. Cost of Wind Turbines

	AOC 15/50	NW100
Wind Turbine & Tower	$ 90,000	$ 230,000
Shipping	$ 25,000	$ 35,000
Installation	$ 50,000	$ 75,000
Foundation	$100,000	$100,000
Total (each)	$265,000	$ 440,000
Annual O&M	$3,000	$4,500

The wind turbine operation and maintenance cost is based on one day of labor ($20/hr) plus a $300 plane charter once every three months for a specialized mechanic from Anchorage, plus one day of labor ($15/hr) every month for a local mechanic. The cost also includes an additional $200 a year to cover any supplies. These numbers result in approximately $0.015 to $0.025 per kWh generated. According to the manufacturers, overhauls of the wind machines are not necessary for the life of the system; therefore, overhaul costs are not included in the analysis.

The balance of system cost can vary depending on the level of wind penetration. The figures listed in Table 5 represent the upper range. Overhead, which includes project coordination, administrative costs, and contingencies, is estimated to be 15-20% of the total balance of system cost.

Table 5. Balance of System Component Costs

Component Description	Cost
Diesel Controls	$ 45,000
Line Extensions	$ 40,000
Insulated Container Shelter	$ 25,000
Supervisory Controller	$ 50,000
Dump Load	$30,000
Overhead/ Other	$60,000
Total	**$250,000**

Depending on the complexity of the system, the total cost for a wind-diesel system is up to $5,000 per kW of rated wind power. These costs are expected to decrease as more experience is gained with the installation of wind turbines in arctic conditions.

The economic benefits of a wind-diesel system result from fuel savings, a potential reduction in diesel O&M and overhaul costs, and the potential value of excess wind energy generated. The use of wind energy also delays the need for additional fuel storage tanks. Approximate values for these parameters are shown in Table 6.

Table 6. Estimated Diesel Generator System Costs

Diesel Fuel Cost	$1.35/gallon ($0.36/liter)
Annual O&M	$5.00 / hour of operation
Overhaul	$30,000 / 10,000 hours
Fuel Storage Tank	$2.50 per gallon of capacity
Storage Tank O&M	$0.40 per gallon of capacity

Since wind turbine components will be added to the existing diesel facility or implemented as part of a major plant overhaul, the diesel generator capital and installation costs are not included in the analysis. In some cases, the initial capital costs of the diesel portion of the plant may be lower when wind energy is included. This possibility, however, has not been considered in the current analysis.

Annual operation and maintenance costs are based on costs incurred by AVEC at several representative villages. These costs have ranged from $2.80 to $9.20 per hour for similar sized generators. Operation and maintenance costs include labor and supplies for regular oil changes and inspections or any unexpected repairs. It does not include the regular operator wages, which would not be affected by reduced diesel run time.

The uncertainty of funding sources makes it difficult to accurately calculate the life-cycle cost of a hybrid system; however, a simple example is given for the case of installing eight 65kW wind turbines in Chevak.

The capital cost with no subsidies would be about $2,350,000. The wind turbines would generate 1,540 MWh of useable energy per year (plus an excess of 340 MWh) and would save $135,000 in diesel fuel per year (100,000 gallons). Based on a loan interest rate of 6% and a general inflation rate of 3%, the levelized cost of energy is $0.13 per kWh.

8. CONCLUSIONS

This paper describes a method to investigate the use of wind generation technology to reduce the dependence on diesel fuel to supply the power needs of rural communities in Alaska. Based on the analysis of electrical use in a number of rural communities, this paper provides a method to estimate the electrical loads; one of the key pieces of information required to conduct any detailed analysis.

A case study was presented to illustrate the use of computer models to quantify fuel savings and calculate the economic feasibility of wind-diesel systems. Although a handful of newly installed hybrid wind-diesel systems currently exist in several Alaskan villages, a comprehensive study of the potential in other villages has not been done. This report is the beginning of that comprehensive effort.

9. ACKNOWLEDGMENTS

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10. REFERENCES

Alaska Village Electric Cooperative (AVEC) website at URL: http://www.avec.org.

Alaska Energy Authority (AEA) website at URL: http://www.aidea.org/aea.htm. Accessed Aug 2003.

Baring-Gould, E.I.; Flowers, L.; Lundsager, P.; Mott, L.; Shirazi, M.; Zimmermann, J. "World Status of Wind Diesel Applications" Proceedings of the 2003 AWEA Conference, Austin TX. June 2003.

Baring-Gould E.I., Flowers, L., Jimenez, T., Lilienthal P., (2000), "Opportunities for Regional Rural Electrification Using Hybrid Power Systems" Proceedings of the 2000 Wind Energy for the 21st Century Technical Symposium, Kassel, Germany. September, 2000.

Department of Community and Economic Development (DCED). Alaska Community Database website at URL: http://www.dced.state.ak.us/cbd/commdb/CF_BLOCK.htm.

Drouihet, S. and Shirazi, M. "Wales, Alaska high Penetration Wind-Diesel Hybrid Power System: Theory of Operation." 77pp. National Renewable Energy Laboratory, Report No. TP-500-31755. 2002.

Drouilhet, S. (2001). "Preparing an Existing Diesel Power Plant for a Wind Hybrid Retrofit: Lessons Learned in the Wales, Alaska, Wind-Diesel Hybrid Power Project." 13 pp.; NREL Report No. CP-500-30586

Hunter, Ray and George Elliot, editors. Wind-Diesel Systems: A guide to the technology and its implementation. Cambridge University Press, Cambridge, UK, 1994.

Meiners, D. Information presented in a presentation at the 2002 DOE/AWEA/CanWEA Wind-Diesel Workshop. URL: http://www.eere.energy.gov/windpoweringamerica/pdfs/workshops/2002_wind_diesel/alaska.pdf

Renewable Energy Research Laboratory (NREL), Renewables for Sustainable Village Power (RSVP) Analytical Models at URL:

www.nrel.gov/villagepower/model.html. Accessed August 2003.

Rural Alaska Sanitation Coalition website. URL: http://www.anhb.org/sub/rasc. Accessed Aug 2003.

U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) website at URL: http://www.eere.energy.gov. Aug 2003.

U.S. DOE Renewable Resource Data Center (RRDC). Wind Energy Resource Atlas of the United States. URL: http://rredc.nrel.gov/wind/pubs/atlas/titlepg.html