WIND POWER
AT GUANTANAMO BAY:

A HYBRID WIND-DIESEL SYSTEM
FOR THE US NAVY
AT GUANTANAMO NAVAL BASE
USING AN ENERGY SAVINGS PERFORMANCE CONTRACT

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by

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ABSTRACT

NORESCO and researchers from the University of Massachusetts' Renewable Energy Research Laboratory and are actively developing what will be the world's largest wind-diesel hybrid electric plant. The pending installation of four 950-kW wind turbines to supplement the 22.8 MW diesel electricity plant at Guantanamo Bay Naval Base is to be carried out under the Federal ESPC (Energy Savings Performance Contracting) Program in partnership with the U.S. Navy.

This paper outlines the initial project development, including the wind measurement, data analysis using measure-correlate-predict (MCP) techniques, turbine siting, potential environmental impacts, time-series modeling of the wind-diesel system, and selection of the wind turbines. The integration of the wind system into the existing diesel power plant was modeled with the Hybrid2 program in order to estimate the wind plant's potential energy contribution and the resulting reduction in diesel fuel use. In addition to technical performance calculations, NORESCO's role in project development and Energy Savings Performance Contract (ESPC) financing is also summarized.

1. INTRODUCTION/BACKGROUND

The US Navy, in partnership with NORESCO is seeking to add a 4-MW wind energy plant to an existing diesel grid on Guantanamo Naval Base (see map in Figure 1). In addition to increasing capacity during peak loads, the purpose of the installation of renewable energy generation will be to reduce diesel fuel usage in the base, while not adversely affecting the power grid or the diesels. The reduced fuel usage benefits the base not only in energy savings and monetary savings but also in the resultant avoided emissions of NO_x, SO_x, CO_2, and particulates.

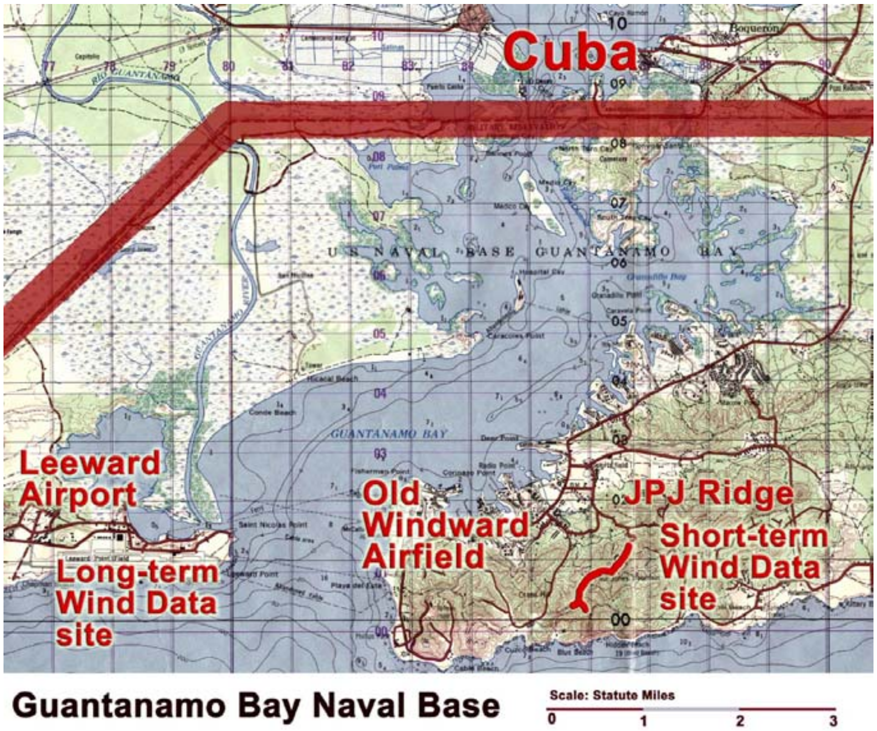

Figure 1. Base map, showing 2 wind data sites, and the ridge proposed for wind development

Under the Federal Energy Savings Performance Contracting (ESPC) Program, NORESCO has proposed the design, provision and installation of wind turbine generators (WTG's) and associated equipment, along with their integration into the existing power plant. In the course of this project, a team of researchers from the University of Massachusetts and Noresco have carried out an analytical modeling study of the wind turbine/diesel hybrid power system, and the development of design concepts for wind turbine systems, including the preparation of bid documents for wind turbine integration into the power grid.

This paper summarizes the analytic modeling of the power system, with detailed descriptions of the existing power system, the wind resource, and the proposed wind power plant. In addition, preliminary economic analyses of the potential system are presented, including a summary of the economic structure used for an ESPC contract vehicle.

2. EXISTING ELECTRICAL POWER SYSTEM

The proposed wind farm will have to be carefully integrated with the existing electrical grid, which is powered by diesel generators. The following section details the existing diesel plant as it pertains to the planning of a wind/diesel hybrid system.

2.1 Diesel Generation System

2.1.1. Diesel generators

Guantanamo Naval Base electricity comes primarily from the first twelve diesel generators shown in Table 1.

The “A”, “B”, “C”, and “N” units are located in the main power plant, located on the “Windward” (east) side of the bay. The “N” units were recently brought in from Norfolk and have been rebuilt. Three other generators in various locations (referred to in table as D and V units) are typically used in standby only and provide only a negligible portion of the base’s power.

Table 1. Guantanamo Diesel Generators

Unit #	Rating kW	Reported minimum operating level* kW	Mfg year	Turbo-charged?	Fuel usage: No load gal/hr	Fuel usage: Full load ** gal/MWh
A1	1000	900	50’s	No	17	82
A2	1000	900		No	17	82
B1	1000	900		No	17	82
C1	2500	1800	60’s	Yes	31	82
C2	2500	1800		Yes	31	82
C3	2500	1500	(90's)	Yes	31	82
C4	2300	1500	60’s	Yes	27	77
C5	2300	1500		Yes	27	77
N1	2500	1800	70’s	Yes	50	81
N2	2500	1800		Yes	50	81
N3	2500	1800		Yes	50	81
N4	2500	1800		Yes	50	81
D100	1500	1500	Backup & standby use			
D105	1500	1500	Backup & standby use			
V13	1500	1500	Backup & standby use			

* *Reported minimum operating level varied from operating records*
** *Full load fuel usage: average gallons of diesel fuel per MWh*

2.1.2. Generator operation

During the year prior to this study, 5-6 generators were typically run during most of the day, with only 4 on-line between 1 am and 4:30 am. In the preceding year only 3 diesels had been kept on-line at night. Nighttime loads have increased due to additional nighttime lighting;

Generators are run using a load-sharing scheme. The 2300 – 2500 kW “C” and “N” machines are the preferred generators, with the older “A” and “B” machines usually generating less than 10% of the electricity. The “A” and “B” machines are used for black-starting the base after an outage. Peak loads typically occur in the afternoon between 12 noon and 5 PM, which we will see corresponds well with the highest wind speeds.

The diesels have over/under-frequency trip setpoints of 57 Hz and 66 Hz respectively. There is reportedly little trouble with harmonics or voltage imbalance.

2.1.3. Spinning reserve & minimum diesel operating level

The minimum operation level is an important variable in the realization of fuel savings from the wind plant; the lower the diesels are allowed to run, the more fuel will be saved. On the other hand, operating diesel generators at low levels can increase maintenance and shorten machine life. A minimum level of spinning reserve must also be maintained. The effect of this tradeoff is considered in more detail in the hybrid system model discussed later in this paper.

2.1.4. Electrical transmission and distribution

Transmission & distribution is at 34.5 kV, 13.2 kV and 4160V, all of which extend to the eastern end of the base, near where wind power is being planned. Much of the base is being converted to 4160V. In conjunction with this conversion, a relay study is being carried out to correct the overcurrent settings of the breakers around the base. The distribution system consists of a number of interlocking loops, but under normal operation many linkages are left open, turning the system into two radial circuits radiating from one of the power plants. Grid stability studies (discussed in more detail below) must take this geometry into consideration.

2.1.5. Diesel control system & strategy

Automatic diesel operation is essential for integration into a hybrid power system. The “C-units” (diesels number C1-C5) have been converted to computer control, including the ability to synchronize, close the circuit breaker, and load share. They are reportedly run in automatic mode most of the time. The N-units were to be converted to automatic control soon after this study was originally performed.

2.1.6. Diesel Fuel consumption

The diesels’ full-load and no-load fuel consumption was estimated by finding a best linear fit for the fuel use data found in the fuel logs, and is listed in Table 1. The fuel logs suggest that the average full-load fuel use for units A, B, C, and N was 80 gal/MWh, or about 30-32% efficient; note that this may have since improved with the more frequent operation of newer diesels.

2.2. Existing electrical loads

2.2.1 Overall electrical loads

Available records of the electrical loads on the island range from 6 to 16 MW in 2001. Since then, loads have been increasing and ranged from 9 to 16 MW in 2002. They can be expected to remain higher for the near future, and future plans indicate that loads may reach 25 MW. Whether the power production will ever exceed usage is an important consideration in the planning of a hybrid electric system. For the time being it was assumed that the proposed wind turbines would never exceed the load requirements, and this still appears to be a safe assumption. Variations in the base's electrical loads will be discussed in a later section.

3. WIND ENERGY RESOURCE

3.1 Wind data sites

Two wind data sites were used to estimate the long-term wind resource at the potential wind farm location. As shown in the map in Figure 1, long-term data from the leeward airport was supplemented by higher accuracy and higher elevation data collected on John Paul Jones (JPJ) ridge. The second site was chosen by NORESCO since it is nearer to the site of the proposed wind farm.

3.1.1 John Paul Jones Ridge site

At this site, wind speed and direction data were recorded hourly during a 4-month period from November 2001 to March 2002. Instruments were mounted at 20 m (66 feet) and 14 m (46 feet) above ground level (AGL), on John Paul Jones (JPJ) Ridge at an elevation of 150 m (492 feet) above sea level. JPJ Ridge is at the end of one of the ridges under consideration. As shown in Figure 2, the other two ridges under consideration were at a lower elevation and nearer the sea to the south.

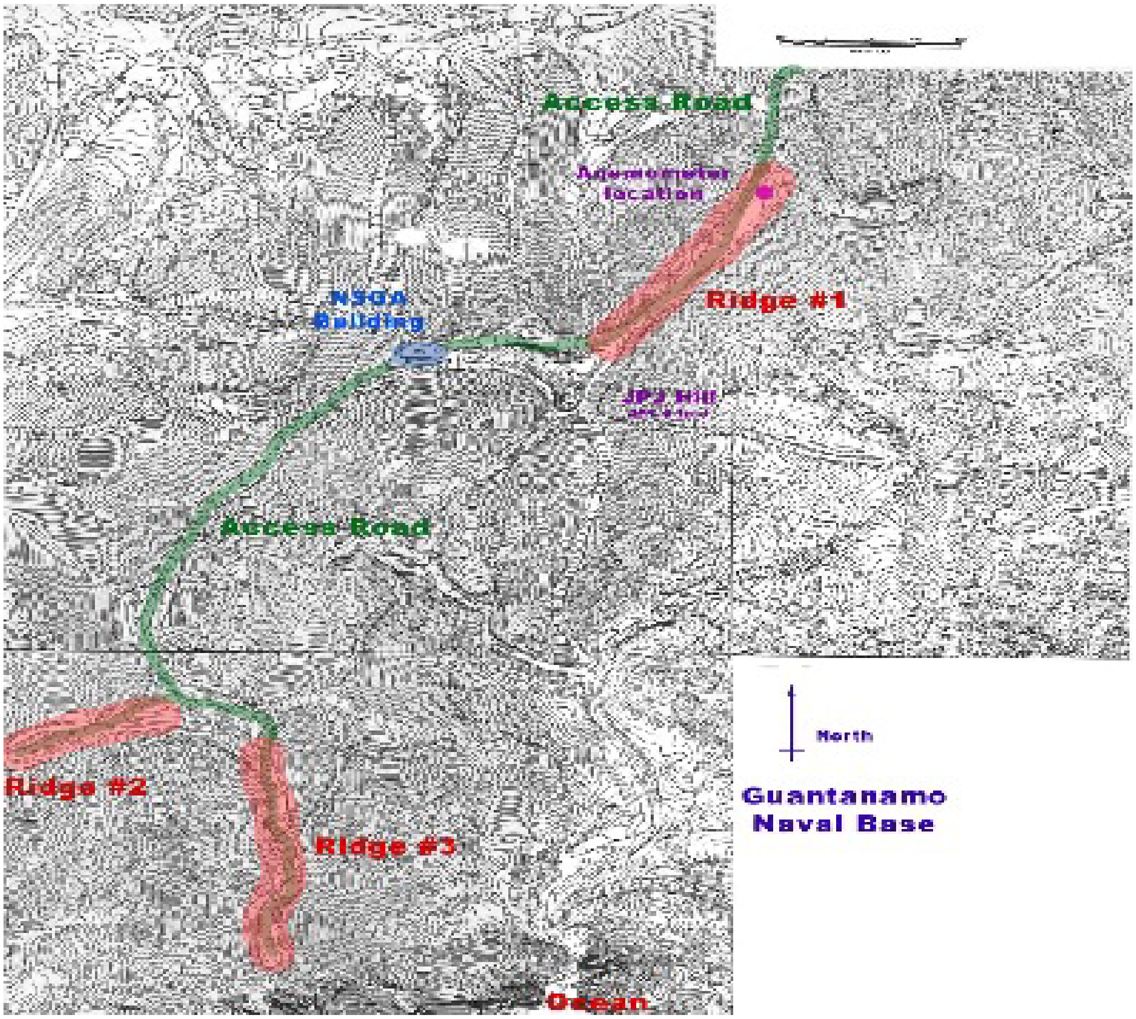

Figure 2: Map of the ridges under consideration

Figure 3 gives a one-week example of the available data at the JPJ site, with the data set average also indicated on the figure.

A wind rose shown in Figure 4 gives the wind direction frequency at this site. As shown in Figure 5, a typical day shows the wind speed increasing during the afternoon hours, which matches the electric load profile well.

Leeward airport

The leeward airport maintains long-term records of hourly wind speeds and directions. The instruments are mounted 15 feet above ground, and the airport is close to sea level. While winds are expected to be considerably lower at this location, this data can be used to predict the long-term trends in the bay's winds. Figures 6 to 8 show wind resource patterns that are similar but not identical to the ridge winds.

3.2 Estimation of Wind Energy Resource at Wind Farm Site

3.2.1 Use of Measure-Correlate-Predict Method

Statistical wind resource estimation methods rely on data from one or more nearby sites to predict the wind resource at a candidate site. One of the most common methods used is the measure-correlate-predict (MCP) method. Measure-correlate-predict (MCP) algorithms are used to predict the wind resource at target sites for wind power development. MCP methods use correlations between wind data measured at the target site, usually over a period of up to a year, and concurrent data at a nearby longer-term reference site. The relationship that is determined between the two data sets, using the concurrent data, is then used with long-term data from the reference site to predict the mean wind speed, wind speed distribution, and direction distribution at the target site. Often the data is binned into direction sectors and separate correlations are determined for each direction sector. Numerous variations on the models or algorithms used for the correlations have been proposed (e.g., Derrick (1993), Landberg and Mortensen (1993) and Joensen, et al. (1999). In general, as noted by Rogers, et al (2003), an approach needs to be chosen which provides unbiased results and that correctly predicts wind speed distributions.

In the MCP method used for this work, both wind speed and direction time series data were available for the reference site (Leeward airport), and wind speed time series data was available for the test site (JPJ Hill).

The wind speed at the reference site was binned into 12 direction sectors of 30 degrees each. Based on the four months of concurrent data, a straight-line fit was made for each sector, between the wind speeds at the reference site and the test site. A comparison of the winds at the Leeward airport and the prospective site is given in Figure 9.

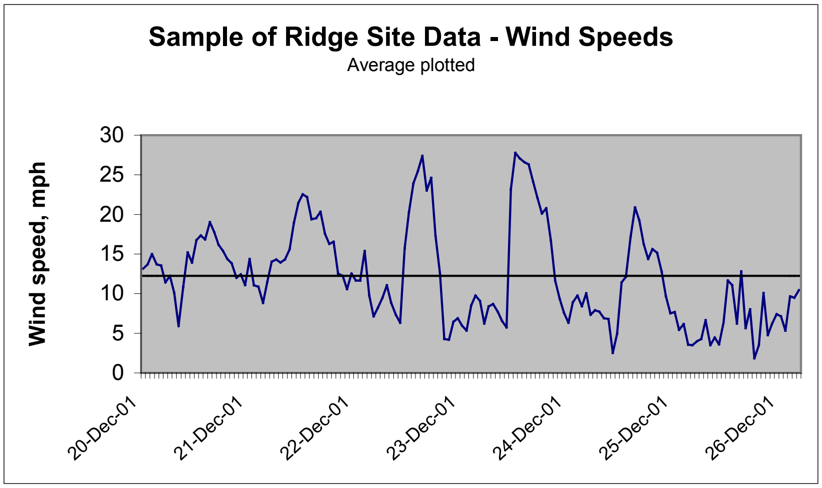

Figure 3. One-week sample of JPJ wind speed data

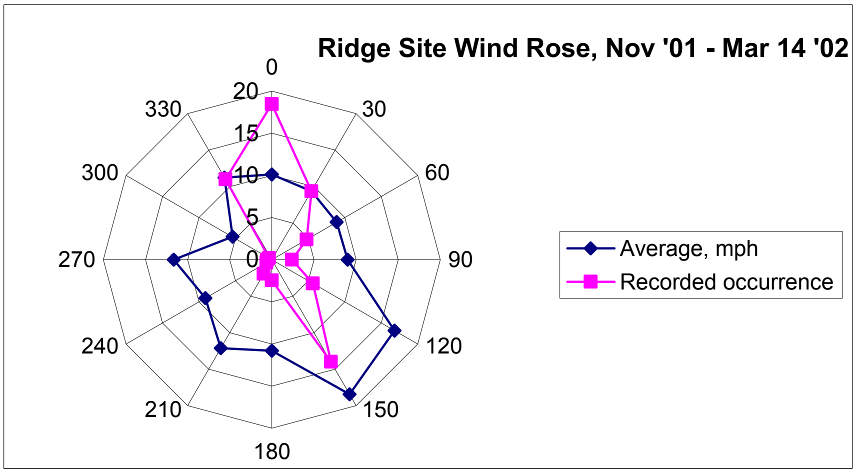

Figure 4. Wind rose for the measurement period on JPJ Ridge

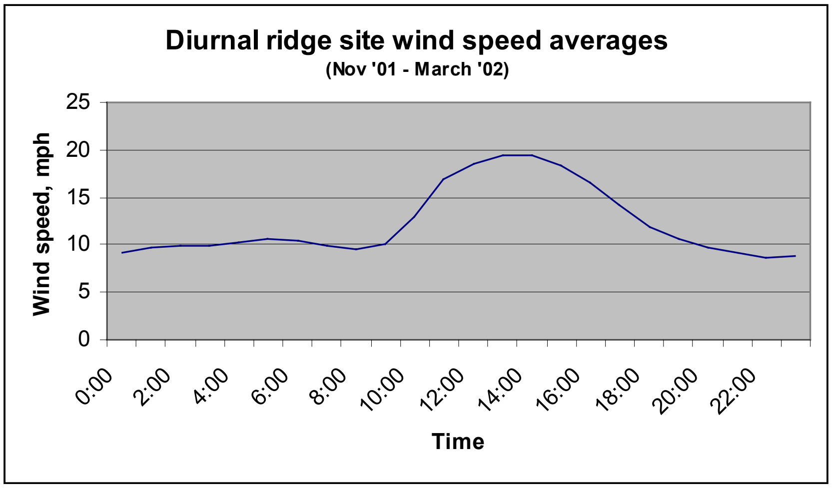

Figure 5. Diurnal wind speeds during the measurement period on JPJ Ridge

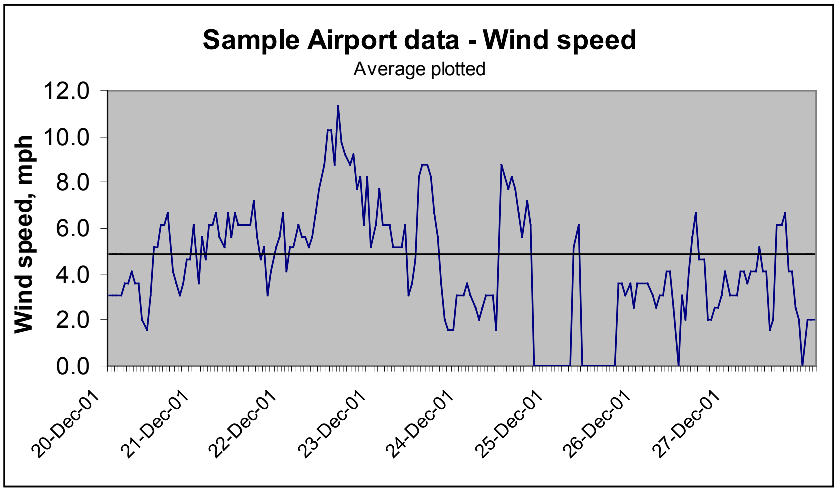

Figure 6. One-week sample of Leeward Airport wind speed data

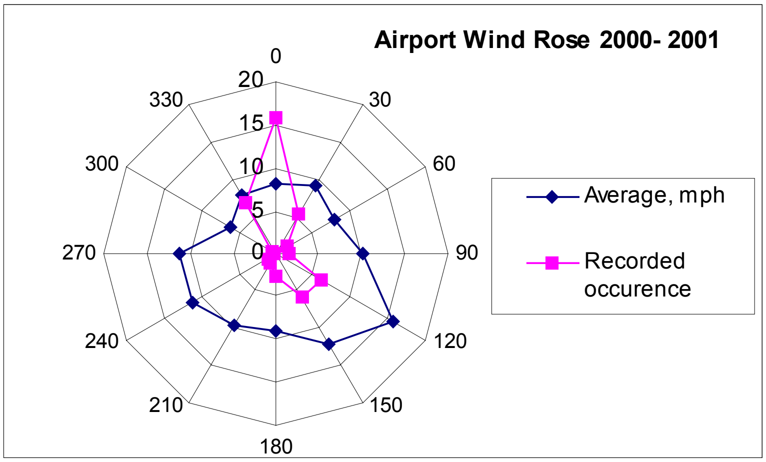

Figure 7. Wind Rose for Leeward Airport site, average of available data

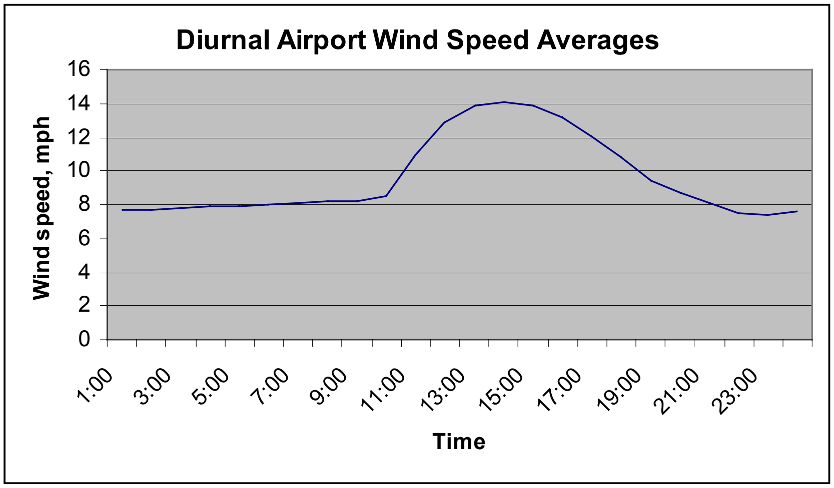

Figure 8. Diurnal pattern of wind speeds at the Leeward Airport, average of available data

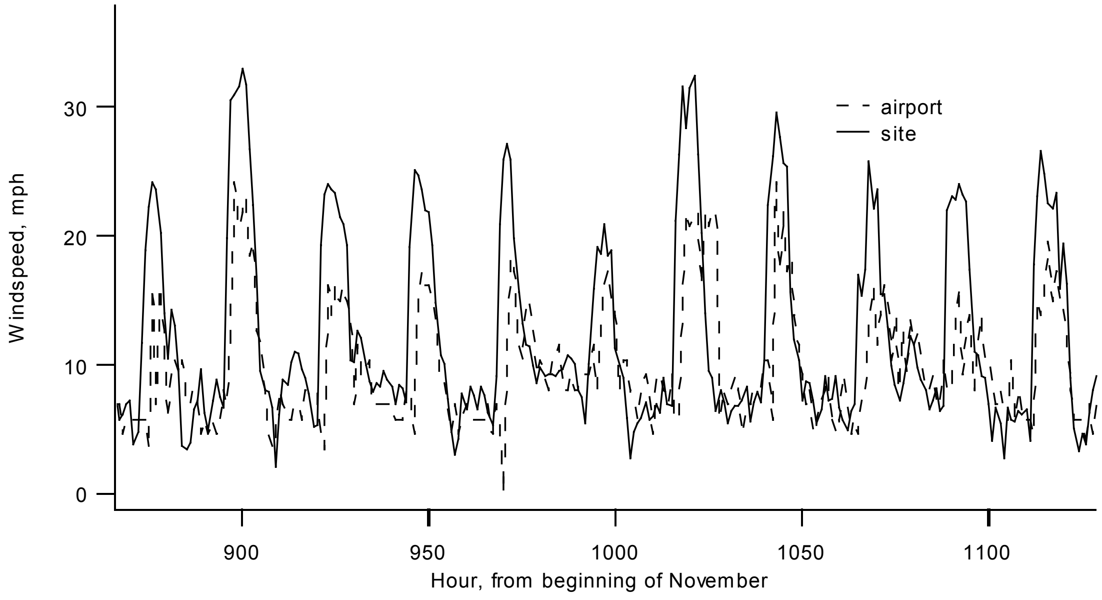

Figure 9. Concurrent data for Ridge and Airport sites, as used in the MCP method

Wind speed data were gathered at a height of 20 m on JPJ Hill, but the winds of interest are at the hub height of the proposed turbines, more likely to be on the order of 50-60 meters. The winds at the lower height are used to predict the higher-altitude winds using the power law:

$$\frac{u(z)}{u(z_r)} = \left(\frac{z}{z_r} \right)^{\alpha}$$

where u(z) is the wind speed at height z, $u(z_r)$ is the reference wind speed at height z_r, and α is the power law exponent.

For the purposes of the initial study, the data was initially scaled from the measurement height of 20 m to an assumed turbine height of 50 m, using a power law exponent of 0.2. Later site data suggested that an exponent of 0.14 would be more appropriate and the calculations were repeated.

3.2.2 Results from Measure-Correlate-Predict Analysis

The mean speed of the JPJ ridge wind data was 5.6 m/s and the mean speed of the airport winds was 4.6 m/s for the respective measurement periods. Comparisons were done in 12 direction sectors, with a straight line fit between the airport and site for each of the directions. The MCP-derived scale factors, along with a height adjustment factor, were then applied to a histogram based on a typical year of airport data. The long-term predicted average wind speed on JPJ ridge was 6.4 m/s when scaled to a height of 50 meters.

Figure 10 shows the relations calculated by the MCP method to predict the wind patterns at the ridge.

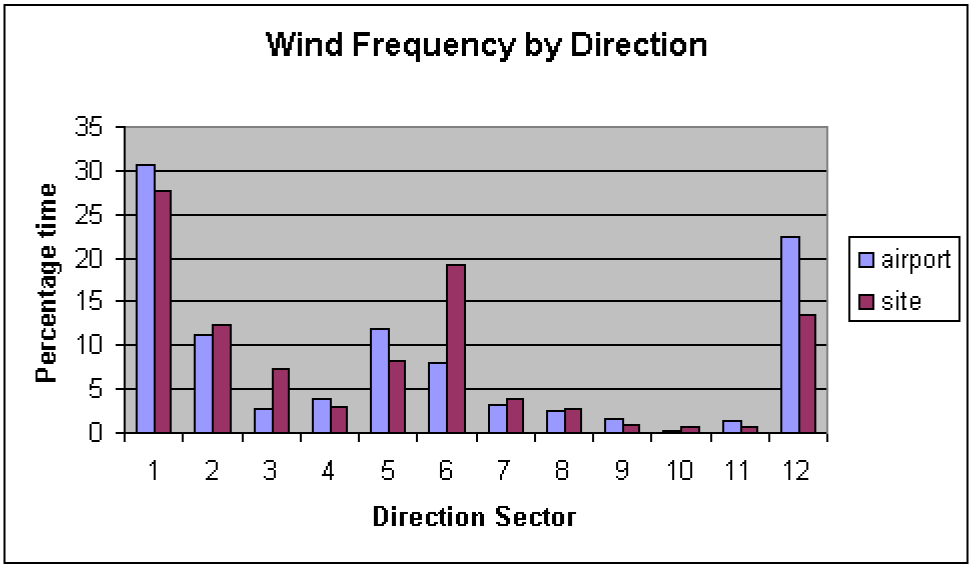

Figure 10. Relative frequencies of wind by sector. Direction sectors 1 to 12 correspond to 0 to 360 degrees in 30-degree increments.

A six-day example of the correlation between airport winds, ridge site winds and MCP-predicted winds for the ridge is given in Figure 11.

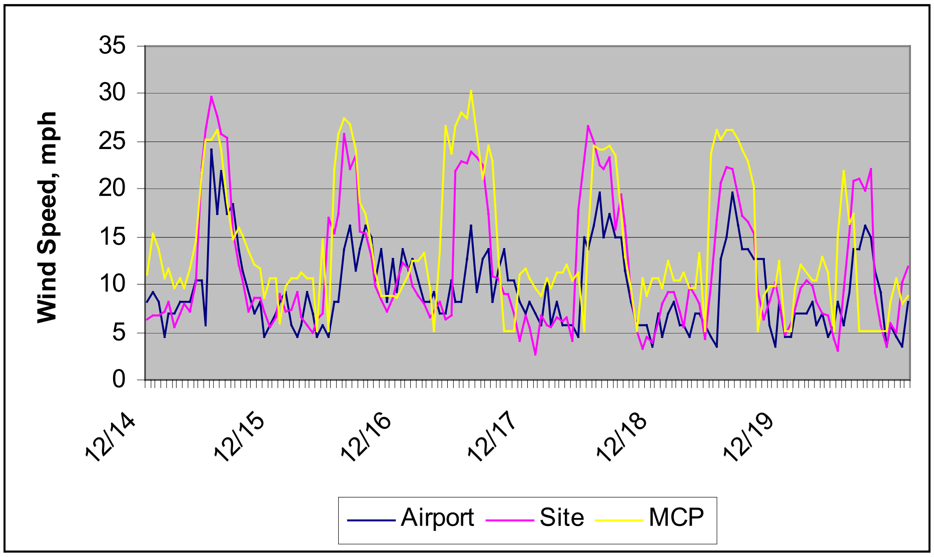

Figure 11. Six-Day sample of the correlation among the two wind-speed data sets and the MCP resulting time series

The initial MCP analysis yielded a long-term predicted annual average wind speed of 6.4 m/s at 50m on the JPJ ridge.

4. SELECTION OF POTENTIAL WIND HYBRID SYSTEM

4.1 Wind/Diesel System Considerations

Although a general discussion of wind diesel systems is beyond the scope of this paper (see for example, Hunter and Elliot, 1994), here we will discuss some general considerations used to select and specify the no-storage type of wind-diesel system used here.

In general, hybrid power systems integrate more than one type of power source to generate power and distribute that power to the system loads. Adding wind power to a diesel system can reduce fuel costs, but also adds complexity to the system due to the potential mismatch between fluctuations in the wind and variations in the load. Wind-diesel hybrid power systems vary in complexity depending on the degree of wind penetration (whose instantaneous value is defined as wind power output divided by electrical load). Higher penetration levels allow greater diesel fuel savings, but require more complex equipment. If the installed wind capacity is great enough that the diesels can be turned off at times of sufficient wind, the controls and equipment required are even more complex. A comparison of wind diesel systems (NREL, 2002) with various levels of penetration is given in Table 2. Table 3 summarizes some other large-scale wind-diesel systems in operation today in the world.

Table 2: NREL's Classification of Wind-Diesel Hybrid Systems by Wind Penetration

Penetration	Class operating characteristics	Penetration	
		Peak Instantaneous	Annual Average
Low	• Diesel runs full time • Wind power reduces net load on diesel • All wind energy goes to primary load • No supervisory control system	< 50%	< 20%
Medium	• Diesel runs full time • At high wind power levels, secondary loads dispatched to ensure sufficient diesel loading • Alternatively, wind turbines are curtailed during high winds and low loads • Requires relatively simple control system	50 – 100%	20 – 50%
High	• Diesels may be shut down during high wind availability • Auxiliary components required to regulate voltage and frequency • Requires sophisticated control system	100 - 400%	50 – 150%

Table 3: Examples of Large-Scale Wind-Diesel Systems in U.S. Territory

Project	Location	Avg. Load kW	Wind kW	Wind machines	Avg. penetration	Peak penetration
Ascension	Atlantic Ocean	2.3 MW	900 kW	4 Micon 225 kW	Low	Low
San Clemente	Off California	850 kW	675 kW	3 Micon 225 kW	20%	80%
Kotzebue	Alaska	2.5 MW	650 kW	10 AOC 15/50	6%	35%
St. Paul	Alaska	70 kW	225 kW	1 Vestas, 225 kW	100%	400%

In specifying the wind-diesel system, an important requirement was a control system that could maintain a high degree of grid stability. Engineers from the US Navy submitted a list of the following specific concerns:

- Not under-loading the diesels
- Overall power quality
- Frequency stability
- Power factor
- Phase balance
- Voltage stability
- Harmonic content

In addition, the wind system installer was required to complete a detailed transient grid stability study to determine the stability of grid voltage and frequency in the face of transient disturbances including:

- Turning WTG's on and off
- The effect of WTG starting inrush
- A fault anywhere in the grid; short circuit response
- Load changes
- Large-scale loss of load, e.g. loss of one of the radial distribution sections due to a fault anywhere on the grid.

In summary, this part of the work determined that a wind farm of a size on the order of 4 MW could be integrated into the Guantanamo electrical power grid.

4.2. Potential Environmental Effects

In siting modern wind farms, the following potentially negative environmental impacts must be weighed against the positive impacts:

- Avian interaction with wind turbines
- Visual impact of wind turbines
- Wind turbine noise
- Electromagnetic interference (EMI) effects

Due to GTMO's site characteristics, as well as its status as a US Naval Base, none of these was likely to be a major issue there, but each were considered in detail and discussed with NORESCO and the Navy. (A more detailed discussion of these issues can be found elsewhere in a number of wind energy engineering references, e.g., Manwell, McGowan, and Rogers, 2002).

In discussing visual impact, visualizations are an indispensable tool. Figure 12 shows a visualization of three turbines on JPJ hill and along the ridge to the south. This and other similar figures were used during numerous briefings to familiarize the base's population with the visual impact of the installation.

Figure 12. Visualization showing three of the four planned wind turbines on JPJ Ridge

4.3. Performance Modeling of Potential System Configurations

The performance and economic system modeling of potential wind-diesel systems for a potential Guantanamo Naval Base installation were carried out using Hybrid2, a hybrid system software model designed at the University of Massachusetts and the National Renewable Energy Laboratory. This design tool is a comprehensive, flexible, user-friendly model that allows a wide range of choices of system components and operating strategies. As detailed in technical papers by the University of Massachusetts (McGowan and Manwell, 1995, 2000), this code was developed from fundamental energy balance considerations and was validated using an experimental wind/diesel simulation system. The model has been used for a large number of technical and economic evaluations of potential wind/diesel systems and to design and optimize such systems. The Hybrid2 model was developed to assist a designer in sizing hybrid power system hardware and in selecting operating options on the basis of overall system performance and economics when site-specific conditions and load profiles are known.

For this study, particular use was made of Hybrid2's ability to predict the level of spinning reserve at each time step. Hybrid2 calculates the excess energy in a single time step and assigns it to a dump load or optional load when one is available and records any excess. The total of these numbers was then summarized as dump load. While Hybrid2 does not directly calculate spinning reserve per se, one can calculate hourly average spinning reserve levels from the output of the simulation with the following equation.

$$\text{Spinning Reserve} = \frac{W_{Diesel}}{\sum_{i=1}^{N_{Diesel}} (P_{Rated,i} * DieselOn_i) * (T)}$$

Where:

W_{Diesel} = Energy produced by diesels in the current time step (kWh)
$P_{Rated,i}$ = Rated power of diesel *i* (kW)
$DieselOn_i$ = Status of diesel at current time step, 1 = On, 0 = Off
N_{Diesel} = Number of diesels used
T = Simulation time step, 1 hour

4.3.1 Hybrid2 Modeling Inputs

Three types of inputs are required for a simulation using Hybrid2. The first are load and resource time series data for the simulation time period. The second type of data involves the operational characteristics of the components that make up the system. The third type of data relates to the engineering economic simulation portion of the software. Information specific to the components, system and economic parameters are required to be able to run an economic simulation. Details of some inputs that are unique to this study are summarized below.

A. Time Series Data Inputs
Electric Load Data
The following load data was made available for this study:

- 11 electronic monthly reports, from July 1st, 2000 to June 20th, 2001 with daily details of power generated, fuel consumed and total run hours of individual diesels or group of diesels. Data for the month of March 2001 was missing.
- Written hourly power level log of individual diesel generators from February 1st, 2001 to June 21st, 2001.

Hourly simulation time series data could not practically be generated directly from the load data provided. However, Hybrid2 allows for the definition of a daily load matrix to be used in simulations with time steps of one hour. A monthly scale factor could then be applied to this matrix to adjust for monthly differences. As shown in Figure 13, data from 10 separate days of the written record were used to generate an average daily load profile.

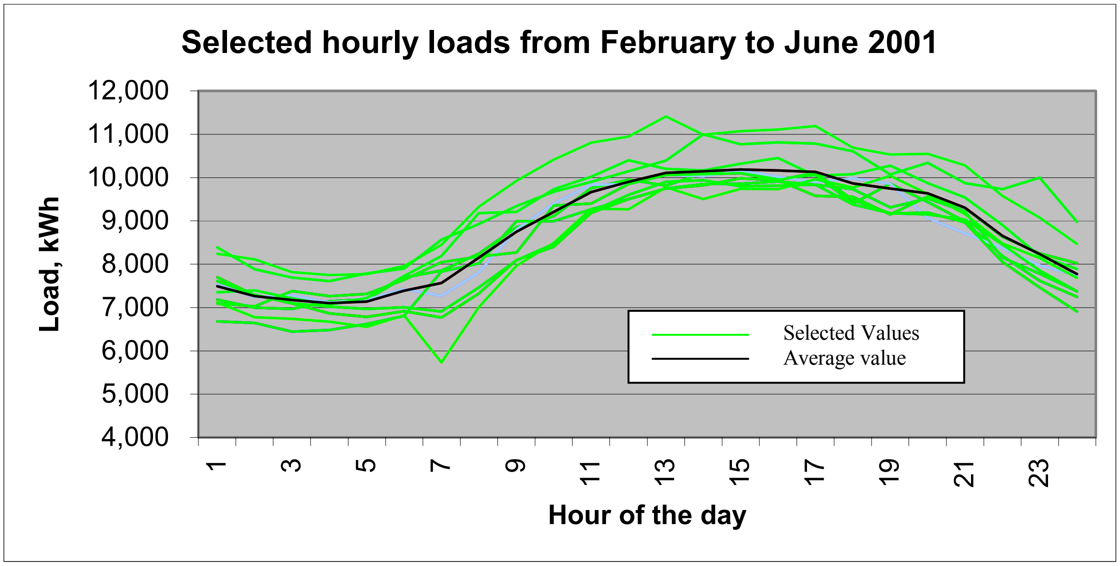

Figure 13. A sample of electric loads showing diurnal variation

Monthly load profiles were determined by fitting the available data to a 3rd order polynomial, and are shown in Figure 14.

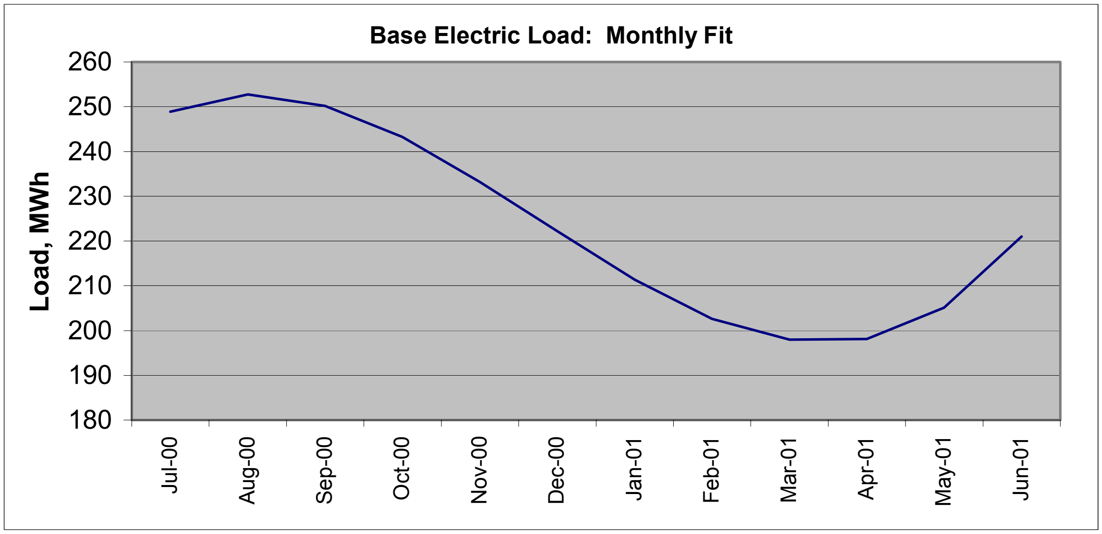

Figure 14. Variation of electric loads over the year: 3rd order polynomial fit

This combined data fitting method generated an hourly load profile that came to within 3% of the average recorded data. This data was further adjusted, however, due to recent population increases at the base. Although no hourly data were available for this recent increase, daily data for the months of January and February 2002 (see Figure 15) indicated that this increase was approximately 17%. Thus, for the simulation a daily total increase of 17% was used.

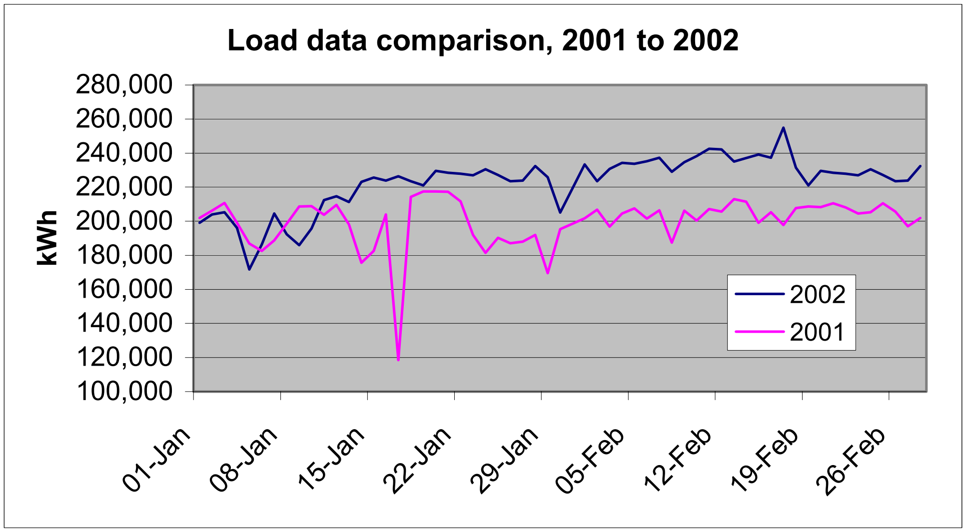

Figure 15. Increase in January & February, electric load profiles, 01' to '02

Wind Speed Data

As previously discussed, based on long-term wind speed and direction data at the Leeward airport and four months of wind speed data on JPJ ridge, the Measure-Correlate-Predict (MCP) method was used to generate a 'representative' year's hourly wind speed profile. This input wind speed data was then scaled from the measurement height of 20m to the wind turbine tower height using a power law exponent of 0.14.

B. Component Specification Inputs

Diesel Generators

As shown previously (in Table 1) a list of diesel generators which included engine and generator model information, age, and power rating, as well as operational information was readily obtained. However, there was not enough information to extract individual diesel fuel curves that were needed for the Hybrid2 simulation. This detail was approximated from available manufacturer information and also was modified to reflect efficiency improvements over the years and a linear fuel curve was developed for each of four types of diesel generator, i.e.:

- 1500 kW generators from 1957,
- 2500 kW generators from the 60's,
- 2300 kW generators from the 60's and
- 2500 kW generators from the early 70's

These fuel curves were then further adjusted by using them to calculate the daily fuel usage assuming operation according to the existing fuel logs. This was then compared to the recorded fuel consumption. Adjustments were then made to the fuel curve to reduce the differences. This iteration was carried out on at least 3 days of data to obtain the best fit.

As a further note, Hybrid2 currently allows the use of only 7 diesel generators in simulations. This is much fewer than the 12 generators available for use at Guantanamo. However, inspection of the daily logs shows that at any given hour between 5 to 7 diesel generators are online. Therefore a simulation that used all the 4 types of generators would adequately simulate the situation at Guantanamo.

Wind Turbines

Three representative wind turbines were chosen for the simulation studies, primarily based on their size variety

- Vestas V47, 660 kW
- NEG-Micon NM52, 900 kW
- Nordex N62, 1300 kW

Their power curves were obtained from the manufacturers' literature and web sites and were input directly into Hybrid2.

4.3.2 Hybrid2 Modeling Results

Diesel-only Base Case

A "diesels-only" base case was modeled in order to validate the model, by creating a comparison point between the simulation and the real system. Thus, a system consisting only of diesel generators was modeled based on the load data. As seen in Table 4, the result of the simulation compared very closely to the available diesel records.

Table 4. Hybrid 2 Simulation Results from Diesel-only Base Case

Annual data (2000-2001)	Recorded	Simulation	Difference
Daily Average Fuel Consumption (gal.)	18,836	18,973	0.7%
Daily Average Power Generated (kWh)	225,492	224,258	0.5%

Spinning reserve was also calculated to be between 32% and 60% of load, which was consistent with values in the provided data.

Wind-Diesel Simulation Results

The Hybrid2 model was used to carry out multiple case studies with variation in the following input variables:

- Minimum allowable diesels run level: 40%, 60%, 75%
- Turbine size, as listed above (in kW)
- Installed capacity, approximately 2, 4, 6, & 10 MW. (Note that 10 MW exceeds the base's electrical loads, and so would require a greater system complexity – this option is not thoroughly modeled here, because a 10 MW installation was not

under serious consideration at this time. Thus, the 10 MW case is included only for reference and an approximate indication of the effects of a large capacity.)

- Load size: base case and 17% increase. (As mentioned above, the hybrid system was modeled both with a load based on 2000-2001 loads, and with a load increased by 17%.)

The following technical outputs of interest were monitored:

- Diesel fuel savings, i.e., reduction in fuel usage
- Spinning reserve
- Degree of penetration
- Wind turbine capacity factor

As an example of the performance output results, Table 5 presents the results for varying total wind turbine installed capacity with the diesel minimum operating level kept constant at 40% and assuming the predicted increased base electrical load. Table 6 shows various turbine performance factors for an approximate 4 MW wind farm using various combinations of the selected wind turbines, assuming the increased base electrical load.

Table 5. Various capacities: Modeled performance assuming the increased load profile (17% increase)

	Rating, kW	**Total Rating, kW**	**% Diesel savings**	**Wind power, kWh**	**Average Penetration (%)**
Vestas	660	1,980	3.8	4,030,000	4.2
		3,960	7.7	8,050,000	8.4
		6,600	12.8	13,400,000	14.0
		9,900	18.9	20,100,000	21.0
NEG-Micon	900	1,800	3.7	3,880,000	4.1
		3,600	7.4	7,760.000	8.1
		6,300	13.0	13,600,000	14.2
		9,900	20.1	21,300,000	22.3
Nordex	1,300	1,300	2.3	2,420,000	2.5
		3,900	6.8	7,250,000	7.6
		6,500	11.4	12,100,000	12.6
		10,400	17.8	19,300,000	20.2

Table 6. Modeled turbine performance assuming increased load profile (17% increase over 2000-2001)

	Total Rated kW	**Wind power, kWh**	**Average Penetration (%)**	**Capacity factor**	**Maximum hourly average penetration (%)***
Vestas (660 kW)	3,960	8,050,000	8.4	23.2	44
NEG-Micon (900 kW)	3,600	7,760,000	8.1	24.6	39
Nordex (1,300 kW)	3,900	7,250,000	7.6	21.2	42

**Note that the Hybrid2 model is a time-series based model, and the current simulation uses a time step of one hour. This means that the greatest precision possible for the maximum penetration is an hourly average value. This is not the same as the Instantaneous Penetration discussed in section 4.1, which would likely be significantly greater.*

Figure 16 illustrates the simulation results for diesel fuel savings as a function of wind turbine capacity. As can be seen, for the range of size considered, larger savings are obtained with the installation of more machines.

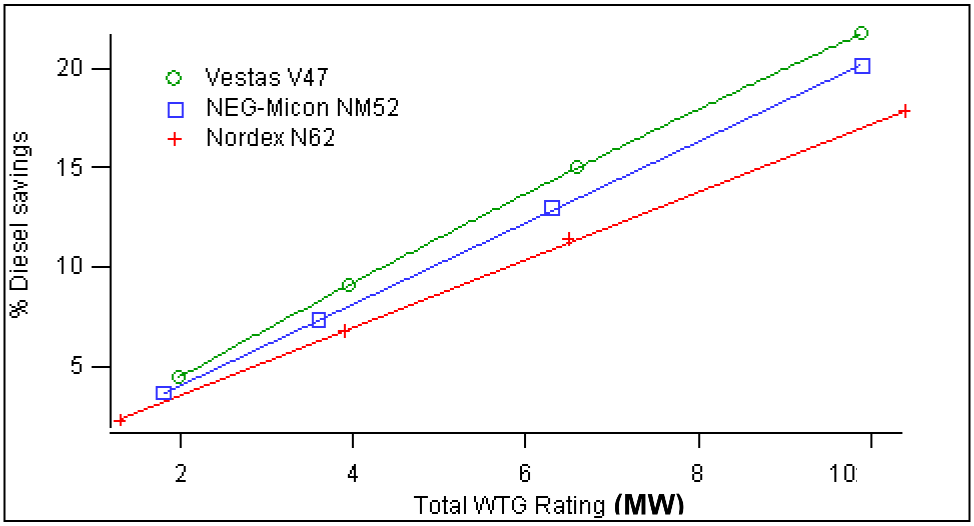

Figure 16. Diesel savings as a function of total wind capacity

The minimum diesel operating level also strongly affects the predicted savings. Figure 17 shows that diesel savings could drop significantly if minimum diesel operating level is raised, from the apparent levels in practice at the time of the study (40-60%) to a level of 75%.

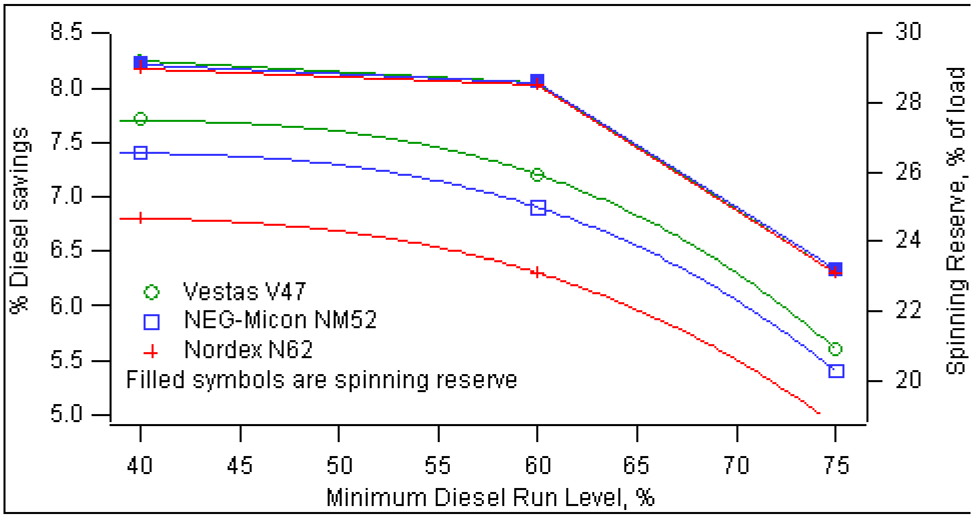

Figure 17. Diesel savings and spinning reserve as a function of minimum allowed diesel run level.

However, here we must make a distinction between the diesels' spinning reserve, as it is normally understood, and the actual available power in reserve in this wind-diesel system. We found that increasing the minimum operating level also increases the probability that generated power is above load demand. This requires the use of dump loads to dissipate the extra power. Results show a significant increase in dumped power with increasing minimum operating level. This dumped power can be considered as available power reserve that can be diverted to useful work whenever needed. Total power reserve should not be affected by increasing the minimum diesel operating level. It only requires the use of a larger dump load to dissipate the excess power.

5. ECONOMIC ANALYSIS

5.1 Conventional Life Cycle Economic Model Using Hybrid 2

Using the results from the previous Hybrid 2 analysis, the cost of energy and payback period could be evaluated over the varied range of system input parameters.

Based on preliminary assumptions on system costs, and the performance results discussed above, the economics of wind power can be examined. The economic advantage of wind power to Guantanamo stems almost entirely from the reduced fuel usage. All three turbine sizes used in the Hybrid2 simulations give a diesel savings total of the same magnitude, averaging about 590,000 gallons a year. The original analysis used the lower diesel costs of the time, \$1.20/gallon, and predicted a gross savings of approximately \$700,000 per year from displaced diesel use. More recent local diesel costs of \$1.50/gallon would result in gross savings of about \$880,000 per year. Furthermore, significant savings in diesel operations and maintenance (O&M) costs can be expected, but are not included here in this conservative estimate. The small differences among the three wind turbines modeled are shown in Table 7. Note that Hybrid2 calculates that system payback will be reached well within 10 years, even with these outdated fuel prices.

Table 7: Results of Hybrid2 simulation, assuming \$1.20/gallon diesel costs

	Units	Vestas	NEG-Micon	Nordex
Rated Capacity	kW	3,960	3,600	3,900
Assumed cost of WT equipment *	\$	\$5,940,000	\$5,400,000	\$5,850,000
Hybrid2 results				
Diesel savings per year	gal	616,744	594,921	549,832
Net Annual Savings	\$/year	\$309,150	\$330,917	\$220,697
Diesel run-hours displaced per year	hours	2,395	2,199	2,025
Simple payback period	years	8.2	7.8	9.1
Levelized Cost of Energy Savings**	¢/kWh	0.29	0.28	0.16

** Not including balance of system*

*** Levelized Cost of Energy Savings is calculated over the base's full annual load, i.e. nearly 100 GWh/year. Energy savings only are included; additional savings in operations and maintenance due to reduced diesel operation will be considerable.*

5.2 NORESCO Model

NORESCO has joined with the US Navy for many years to develop, install and finance both energy conservation and efficient energy production projects at Navy Bases within the US and around the world. For most of these projects the legal contract used is referred to as a "Energy Savings Performance Contract" or ESPC.

In this type of contract, NORESCO works closely with the managers and staff of government agencies and then prepares and submits detailed recommendation for facility improvements and upgrades. If approved, these fixed price projects are built and commissioned by NORESCO, at no cost to the government. These projects must produce extensive and viable energy and/or operational & maintenance savings (E+O&M). NORESCO is required to prove and guarantee these savings. The government uses these savings to repay NORESCO. There is no net change in the facility's cash flow, and the agency (e.g. the Navy) collects all the savings once the contact finance term is over. A schematic of the ESPC procedure is shown in Figure 18.

Since 1999 NORESCO has worked at the US Navy base in Guantanamo Bay, Cuba (GTMO). As noted above, this base is self-contained; it produces all its own water through desalination plants and currently produces its own electricity using diesel generators. NORESCO's first projects at GTMO included the design, coordination, financing, and installation of energy efficient lights and efficient water fixtures through the Base. Over 1200 buildings were included in this work. The project substantially reduced the energy and water consumption for the Base.

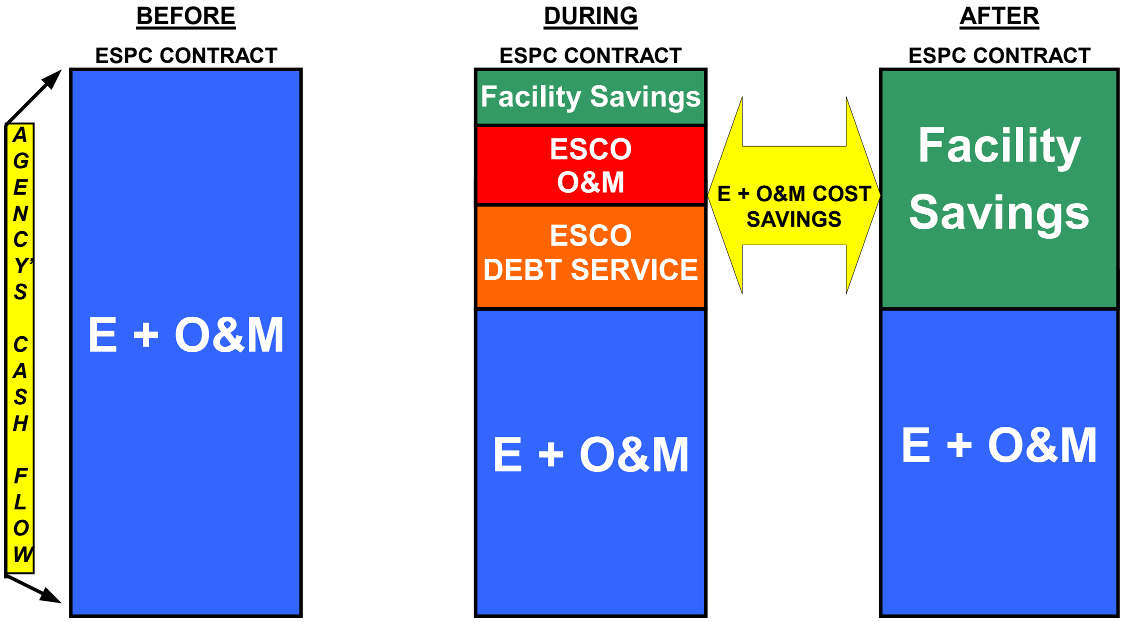

Figure 18. Energy Savings Performance Contracting: dividing the savings "pie" during and after the contract

In addition to the energy and water conservation projects, as well as the wind turbine project, NORESCO is also installing an additional 7 megawatts of new efficient diesel generators at GTMO. By the end of 2004 NORESCO will have completed over $26 million worth of improvements to GTMO. The guaranteed energy and O&M savings will keep the repayment term to just 12 years.

6. SELECTION OF WIND TURBINES AND SYSTEM INTEGRATION DESIGNER

6.1 Bid Process

NORESCO contracted with the University of Massachusetts' Renewable Energy Research Laboratory (RERL) not only to study the appropriateness of a wind-diesel hybrid power system as discussed above, but further to help NORESCO to seek and choose a subcontractor to design, supply and install the system. RERL developed bid specifications and related documents, and distributed them to potential bidders. NORESCO, RERL, and representatives from six interested companies visited Guantanamo Bay in April 2002. Three completed bids were received by the deadline a few months later.

6.2 Final Choice of System

The researchers at RERL reviewed and made recommendations to NORESCO on the merits of each subcontractor proposal. Detailed analysis showed estimated energy output, specific logistic requirements for installation, and prior experience for installers at remote locations.

The three bidders were invited to make presentations and hold discussions with the NORESCO team of Developers and Engineers. Under an ESPC, NORESCO and the Navy do not have to automatically award the work to the lowest bidder, but can judge and award the work to the subcontractor that brings the *best overall value*.

NORESCO choose a subcontractor team led by Pacific Industrial Electric with EnXco and Northern Power, using NEG Micon machines. This strong team brought substantial experience in installing wind turbines in difficult locations, in maintaining these machines, and in the interconnection to existing power grids. NEG Micon machines have been successfully used at two other remote US military facilities that are wind/diesel hybrid power plants. These facilities, the US Navy Air Station at San Clemente, off the coast of California, and US Air Force Space Command facility on Ascension Island, are summarized in Table 3.

7. CURRENT STATUS OF PROJECT

In September of 2003, the Navy gave the approval for NORESCO to move forward with the installation of the wind turbine system at GTMO. In its first task, NORESCO then commissioned a detailed grid stability study to ascertain the effect of the wind turbines on the existing electrical grid. This study recommended an interconnection point at a larger substation than originally planned, and the interconnect design was revised.

The access roads and foundations are to be installed in the spring of 2004. The wind turbines are scheduled for delivery direct from Europe in June of 2004, with installation in July and August. A 250-ton crane is being brought to GTMO for erection. The Navy Base also has a 175-ton crane on-site for secondary use during erection and for any long-term O&M needs.

This record-breaking project has the full support of the US Navy. The installation of nearly 4 MW of wind power on the JPJ Ridge will make GTMO the world's largest wind-diesel hybrid utility. These wind turbines will stand 180 feet tall and their power will be fed directly into the Base's distribution system. At peak power output, the four turbines will produce approximately 20 to 25 percent of the Base's electric demand. In a year of normal wind speeds, they will produce over 7,200,000 kWh. The wind turbines will be highly visible proof of the Navy's commitment to utilize a clean energy resource, to reduce dependence on non-renewable fuels, and to displace the greenhouse emissions of CO_2 by the diesel generators by over 13,000,000 pounds per year.

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