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Subcontractor Report

Performance and Economics of a Wind-Diesel Hybrid Energy System: Naval Air Landing Field, San Clemente Island, California

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DOE Strategic Environmental Development Research Program

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CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

FOREWORD

This report was prepared as an account of work for others funding contract, sponsored by the Department of Defense (DoD) Strategic Environmental Research and Development Program (SERDP) under Department of Energy (DOE) Contract # DE-AC02-83CH10093.

This report provides an overview of the wind resource, economics and operation of the recently installed wind turbines in conjunction with the with diesel power for the Naval Air Landing Field (NALF), San Clemente Island (SCI), California Project.

The purpose of the SERDP and Federal Energy Management Program (FEMP) funded installation is to use wind power, a form of renewable energy, to decrease the Navy's dependency on fossil fuel at San Clemente Island. Wind-powered electrical generation would allow a reduction in the current use of diesel-powered generators on the island. The primary goal of the SCI wind power system is to operate with the existing diesel power plant and provide equivalent or better power quality and system reliability than the existing diesel system. The wind system is intended to reduce, as far as possible, the use of diesel fuel and the inherent generation of nitrogen-oxide emissions and other pollutants.

The first two NM 225/30 225kW wind turbines were installed and started shake-down operations on February 5, 1998. This report describes the initial operational data gathered from the February through January 1999, as well as the SCI wind resource and initial cost of energy provided by the wind turbines on SCI. In support of this objective, several years of data on the wind resources of San Clemente Island was collected and compared to historical data. The wind resource data was used as input to economic and feasibility studies for a wind-diesel hybrid installation for San Clemente Island.

Timothy L. Olsen, an engineering consultant, was contracted by National Renewable Energy Laboratory (NREL) to assist with data reduction analysis, research historical wind resource data, perform wind-diesel hybrid analysis, and assist in the generation of this report.

ACKNOWLEDGMENTS

The authors wish to acknowledge major contributions to the success of this project by the following people: Ed Cannon of National Renewable Energy Laboratory (NREL), the Strategic Environmental Research and Development Program (SERDP) project manager, and Neil Kelley of NREL, the meteorological consultant. Bob Keller and crew of Mountain Valley Energy, who installed, commissioned, and helped operate the meteorological towers and instrumentation. Extensive typing, editing, and graph building was provided by Roni Olsen of Highline Editions.

Scott Davis, the Utilities Supervisor at San Clemente Island (SCI), advised on aspects of SCI facilities, costs, operations, and detailed breakdowns for the SCI diesel plant operations and costs. Scott also manages daily wind energy project activities. More detailed diesel cost information was provided by Valre Kehler and Mike Stevens of Valley Detroit Diesel Allison. Additional support was provided by Brian Cable, the SCI project manager of Naval Facilities Engineering Service Center (NFESC); Ken Nicoll, past Division Director of Public Works Center (PWC); Diana Bendle, Assistant Operations PWC.

Tom Brule, Division Director at PWC San Diego, and Joyce Sengpaseuth, the electrical engineer at PWC San Diego made the site available for study and arranged travel to and from SCI. Scott Miller of NFESC assisted with meteorological instrumentation, and the rest of the SCI Navy support staff assisted with this project in countless ways. And yes, one other that kept the SCI Wind Energy dream alive – Norm Groth, USN COGEN-SD Director.

Each of these people deserves special thanks for their role in bringing this project together.

EXECUTIVE SUMMARY

In 1991, Congress authorized the Strategic Environmental Research and Development Program (SERDP) to help Department of Defense (DoD) meet their environmental obligations. The SERDP efforts included the use of alternative energies to reduce emissions.

The long-term objectives of the U.S. Navy for San Clemente Island (SCI) are to install about 8 MW of wind capacity and to develop a pumped-hydroelectric storage system, using the ocean as the lower reservoir. SCI's electrical system is powered with diesel generators, using wind energy to reduce the overall diesel system operating costs.

To accomplish this mission, National Renewable Energy Laboratory (NREL), with the aid of Naval Facilities Engineering Service Center (NFESC), was charged with collecting wind resource data, and then providing the wind turbine generation system installations. The first two turbine installations were funded through DOE/SERDP, the third is being funded by the Department of Energy (DOE) Federal Energy Management Program (FEMP) funds, and the fourth will be funded through DoD Navy funds. This report summarizes the results of those tasks and the operational data learned to date.

The 1995 through 1998 wind resource at the designated SCI Wind Turbine Site has an annual average wind speed of 6.1 m/s (11.8 knots) as measured by NREL and NFESC on a 42.7 m (140 foot) meteorological tower. Data were collected between August 1995 and January 1999 with several sections missing throughout.

This work presents a study of the operation of a wind-diesel hybrid system using two wind turbines, along with predictions for an expansion up to 4 wind turbines. The study shows that wind energy can be cost effective in this application. As the third and fourth wind turbines are added, further savings are expected as the power plant can then run with fewer or smaller diesel engines. Further additions would start to see diminishing savings. Additional wind turbine installations may be limited at SCI, as the island has 7000 protected archeological sites and other Navy facilities have priority. Higher wind potential is available at the southeast end of the island, but that region is used for the bombing range and is off limits.

Using two 225 kW wind turbines, the wind energy COE of $0.142/kWh helps reduce the wind-diesel hybrid system COE from the baseline $0.476/kWh to $0.461/kWh. This reduces system COE by 3.2%. The payback period is 6.5 years, the internal rate of return 14.4%. The four-turbine case had a wind energy COE of $0.139/kWh and a hybrid system COE of $0.447/kWh, saving 6.1%. The payback period is 6.3 years, the internal rate of return 14.8%. The COE for this case is relatively insensitive to annual average wind speed, varying 2.6% for a 17.5% change in wind speed. But the payback period is quite sensitive to wind speed, varying 28% to 63% for a 17.5% change in wind speed.

As a preliminary review, this study used 1-hour average wind and load data for the hybrid system modeling to develop a general sense of economic tradeoffs. Dynamic load management should be addressed using load and wind data at shorter intervals (1 minute or less) to study system dynamics.

1.0 INTRODUCTION

This report outlines and summarizes the local wind resource and evaluates the costs and benefits of supplementing the current diesel-powered energy system with wind turbines at the Naval Auxiliary Landing Field, San Clemente Island, California. This renewable electrical power generation provides a reduction of emissions from the diesel power plant. Specifically, the project began with two operational 225 kW wind turbines, and construction has begun on a third turbine, which should be installed and online by July, 1999.

In Section 2.0 the San Clemente Island (SCI) site, naval operations, and current energy system are described, as are the data collection and analysis procedures. Section 3.0 presents the wind resource data and its analysis results, including historical wind speed averages, recent annual records, diurnal wind speeds, and annual wind roses. Sections 4.0 and 5.0 present the conceptual design and cost analysis of a hybrid wind and diesel energy system on SCI, with conclusions following in Section 6. Appendix A presents summary pages of the hybrid system spreadsheet model. Appendix B contains actual system operating data. Appendix C presents the results of a preliminary load and fuel analysis. Appendix D presents Wind-Diesel System Operational Guidelines developed by NREL and the RMH Group (Lakewood, Colorado).

2.0 BACKGROUND

2.1 San Clemente Island

Installation Setting

SCI is one of the Navy's largest real estate assets and is among its most unique installations. SCI is the southernmost of the eight Channel Islands located off the southern California coast, lying approximately 89 km (55 mi) southwest of Long Beach and 135 km (84 mi) northwest of San Diego. The next nearest land-mass to SCI is Santa Catalina Island, lying approximately 40 km (25 mi) away between SCI and the mainland. SCI's geographical center is 32° 54'N, 118° 29'W.

The Island is approximately 34 km (21 mi) in length, with a land area of about 148 km^2 (57 mi^2, or 35,540 acres), making it one of the larger Channel Islands shown in Figure 1. The rugged southern third of the island has an average width of about 6.4 km (4 mi), with the remainder tapering to 1.6 km 1(mi) across at the flatter and lower north end.

SCI is considered the most biologically and historically distinctive coastal island owned by the United States. Because the island supports unique natural, cultural, and anthropologic resources as well as a variety of activities for Naval operations and training.

The island, generally treeless, is relatively flat on top and drops off sharply on the east side with a more gradual slope to the ocean on the west side. The interior terrain is a rolling mesa, with little vegetation, mostly coarse grasses and few large shrubs. Its highest point, Vista View Point, is 592 m (1,943 feet) at the southwestern portion of SCI.

The San Clemente Island wind turbine site, Figure 2, is located along Telemetry Road in the island's north-central portion (33° 59' N, 118° 53' W).

Prevailing winds on SCI are from the west and northwest and are moderate and steady most of the year. The average wind speed at the wind turbine site is 6.1 m/s (11.8 knots) and seasonal variation is small.

Climate
SCI's climate is distinctly maritime, with cool summers and mild winters. Except for fog and overcast conditions and generally cooler year-round temperatures, the weather is similar to that of the southern California mainland coastal region [1].

Temperature
One of the outstanding features of SCI's climate is the narrow temperature range, with mean winter temperature just –12.2°C (10F) lower than the mean summer temperature. Mean annual temperature at the lower elevations is about 15.6°C (60°F), 16.6°C (62°F) at the higher elevations. Temperatures above 32.2°C (90°F) are rare, but occasionally when Santa Ana wind conditions occur between August and October, temperatures of 32.2°C (90°F) and even 37.8°C (100°F) have been recorded. No temperatures below freezing have ever been recorded at the location of the air field station, but at the higher elevations such as Mt Thirst such temperatures appear to occur according to the Navy based public utility crews.

Humidity
High relative humidity is experienced throughout the year with an annual average of 78 percent. The exception occurs during Santa Ana conditions when the relative humidity is generally less than 25 percent [1].

Winds
Gale force winds are common at higher elevations during the winter, but are infrequent elsewhere on the Island. Average wind speeds measured at the airfield are less than ten knots. The airfield sits at a low elevation next to a rise in the land, which can deflect or shelter the wind.

Precipitation
Annual precipitation averages just five to eight inches, with the majority falling between November and April, and the driest period being June to September. Snowfall has been reported at the highest elevations on the Island, Mt. Thirst and Mt. Vista, but in minimal amounts. Occasionally small hail accompanies the passage of strong storm fronts [1].

2.2 Naval Installation Mission

The Naval Auxiliary Landing Field (NALF), SCI serves a variety of weapons research, development, testing and evaluation activities, and a number of military training functions as well. It is used primarily by several major Naval tenant commands, but is also used by research divisions of government agencies and private companies working on government contracts. The Island is administered by the Commanding Officer, Naval Air Station North Island. SCI's relative isolation, restricted airspace, variable topography, adjacent deep seas and clear water conditions permit a great deal of flexibility in accommodating specific testing and training programs [1].

Figure 1: SCI Location Map
Source: San Clemente Island Site Manual

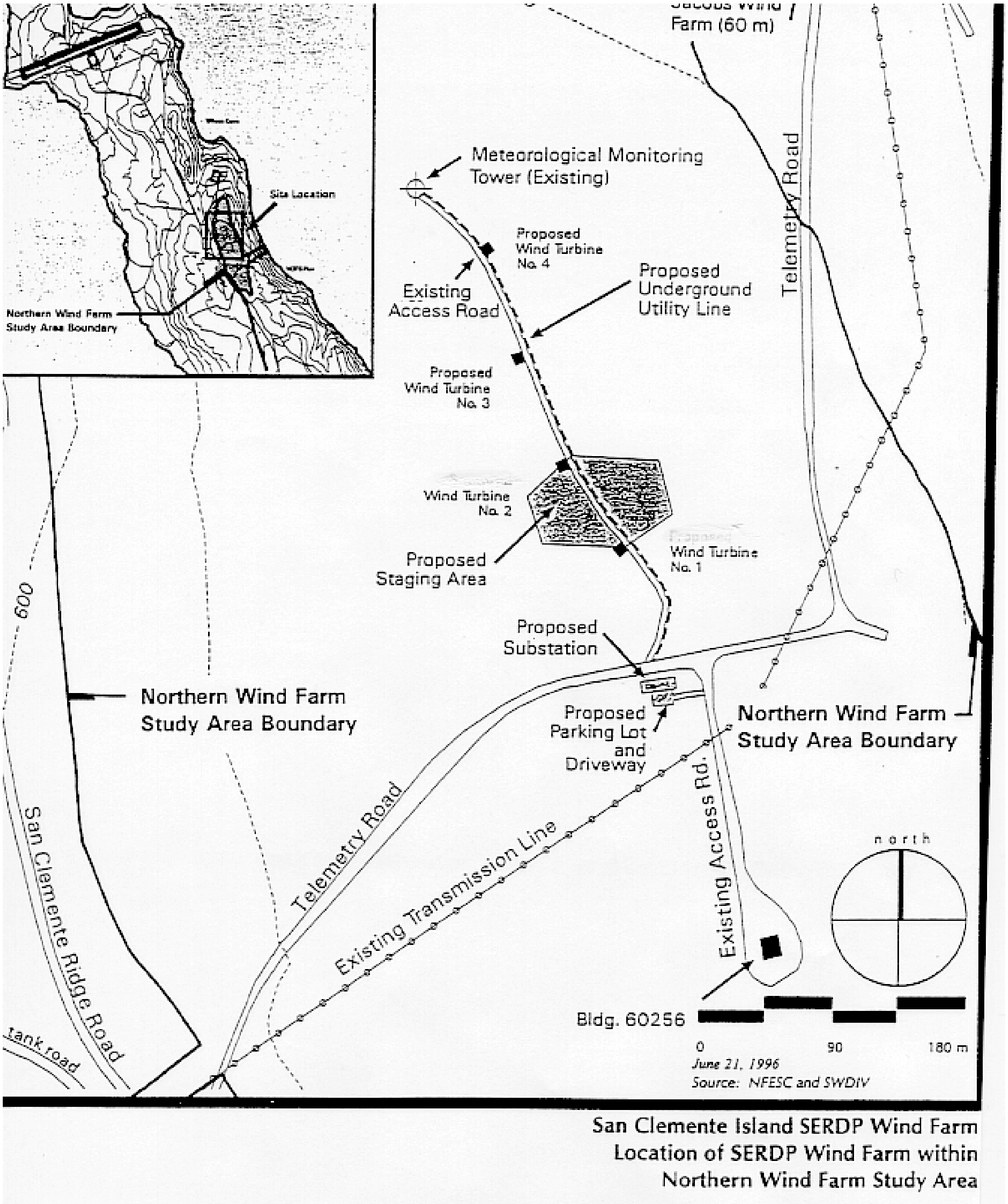

Figure 2: SCI Wind Farm Location Map

Source: USN NFESC and SWDIV Environmental Assessment Report

2.3 Energy Demand

Energy production information follows in Table 1. The current (1998) average hourly electrical demand at SCI is 846 kWh; the hourly average peak is 1350 kW. The SCI electrical power system supplied 7.42 million kWh in 1998, up from 6.15 million kWh in 1996.

Table 1: SCI System Demand Statistics

Year		1996	1997	1998	San Nicolas Island 1995
Peak daily demand	(kWh)	22,400	25,900	26,788	N/A
Low daily demand	(kWh)	12,250	14,000	13,650	N/A
Average hourly demand	(kWh)	711	785	846	771
Average daily demand	(kWh)	17,075	18,838	20,320	19,275
Average monthly demand	(kWh)	512,269	565,146	618,080	586,281
Peak monthly demand	(kWh)	547,100	724,150	708,438	N/A
Low monthly demand	(kWh)	478,000	523,250	578,025	N/A
Annual energy production	(kWh)	6,147,230	6,781,750	7,416,959	6,753,000
Annual energy from diesel	(kWh)	6,147,230	6,781,750	6,631,021	6,753,000
Annual fuel consumption	(liter)	1,983,120	2,033,260	2,074,240	1,996,584
Annual fuel consumption	(gal)	523,942	537,190	547,958	527,499
Energy / Fuel ratio	(kWh/l)	3.10	3.34	3.58	3.38
Energy / Fuel ratio	(kWh/gal)	11.7	12.6	13.54	12.8
Demand growth	(%)	–	10.3	9.4	–

Source: SCI Public Works Center

The load frequency distribution in Figure 3 shows predominant operation between 700 kW and 1000 kW, with peaks up to 1400 kW. Annual diurnal loads are shown in Figure 4. These figures are based on the composite data set using original 1998 loads data. Included with the data set are daily energy production and monthly fuel consumption. Annual records of monthly energy production and fuel consumption are shown in Figures 5 and 6, and the relationship between the two in Figure 7.

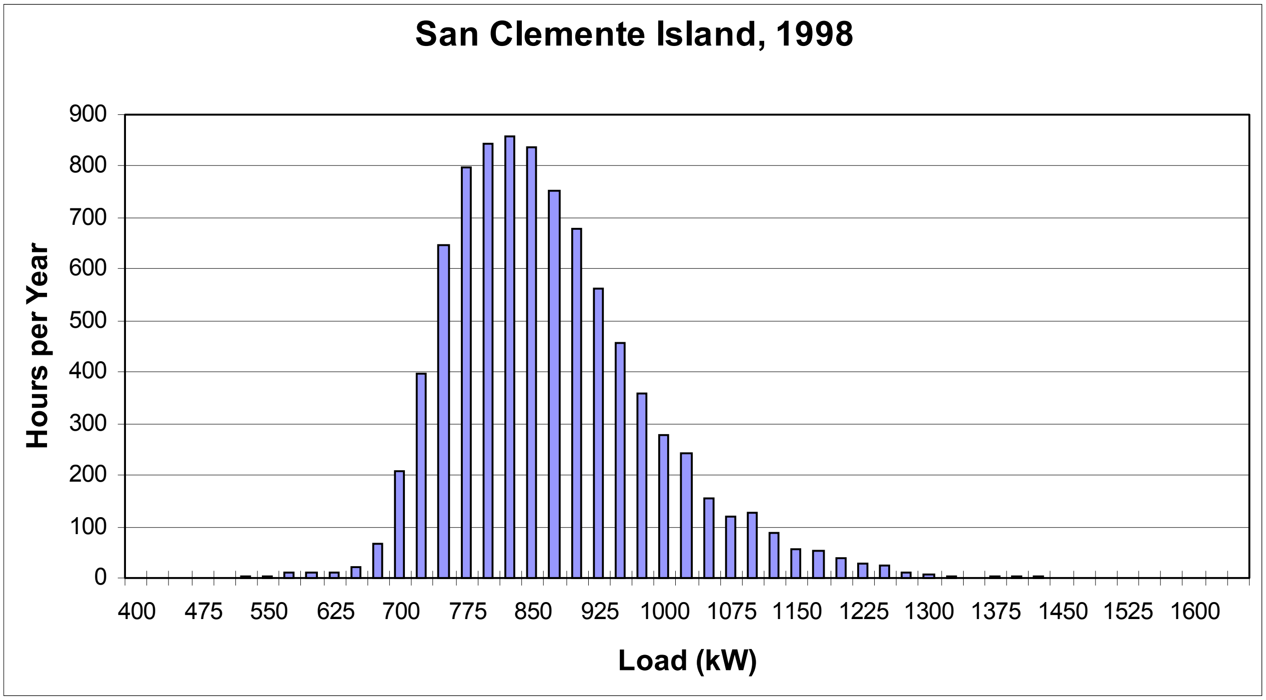

Figure 3: SCI Load Frequency Distribution

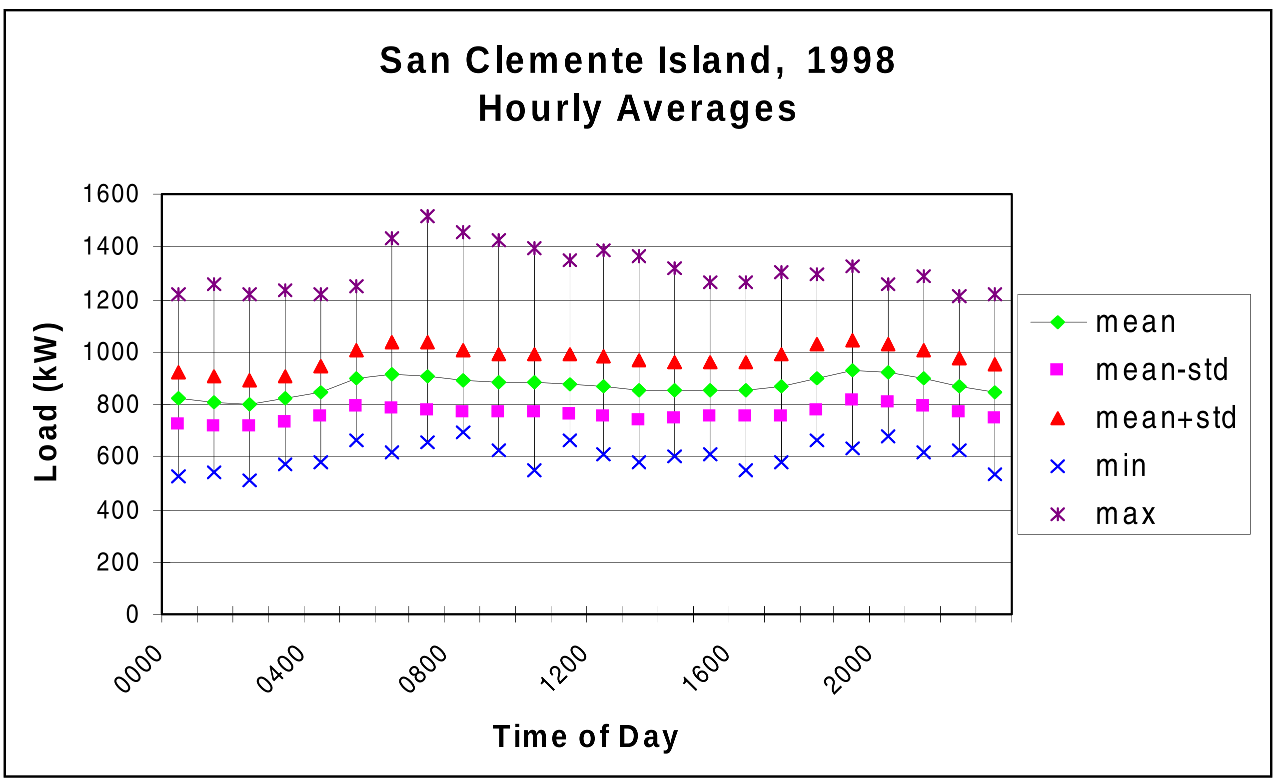

Figure 4: SCI Annual Average Diurnal Load

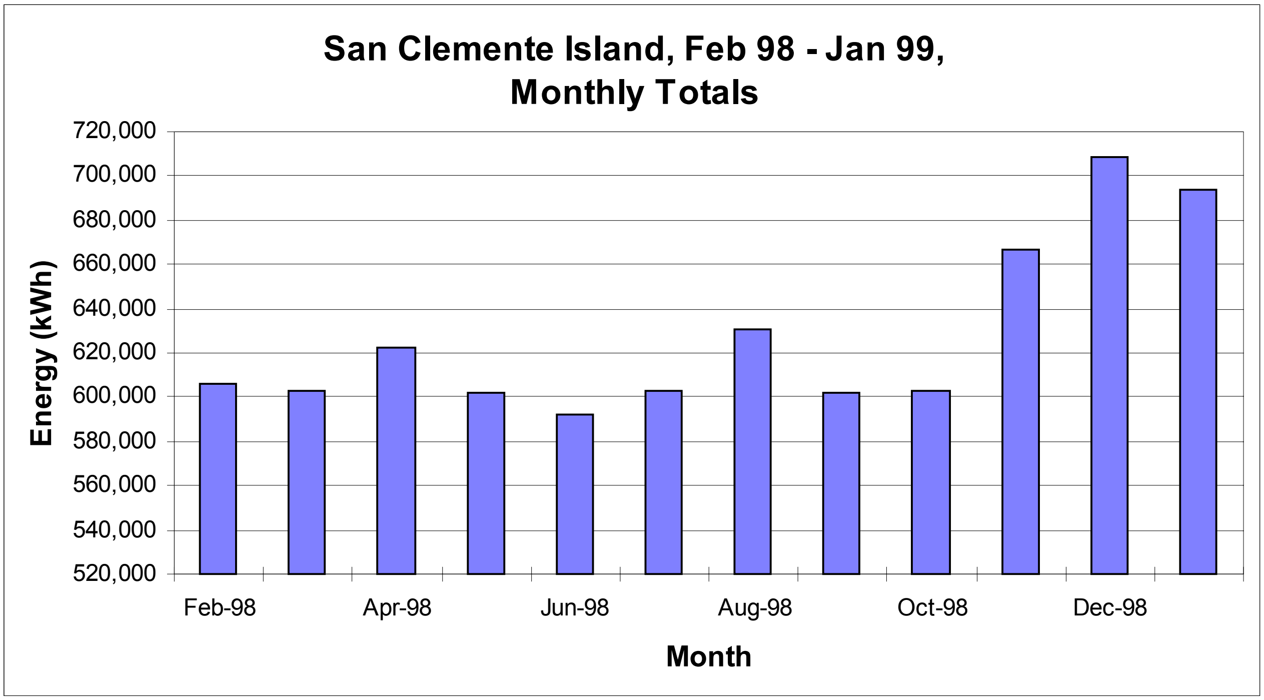

Figure 5: SCI Annual Energy Production Record

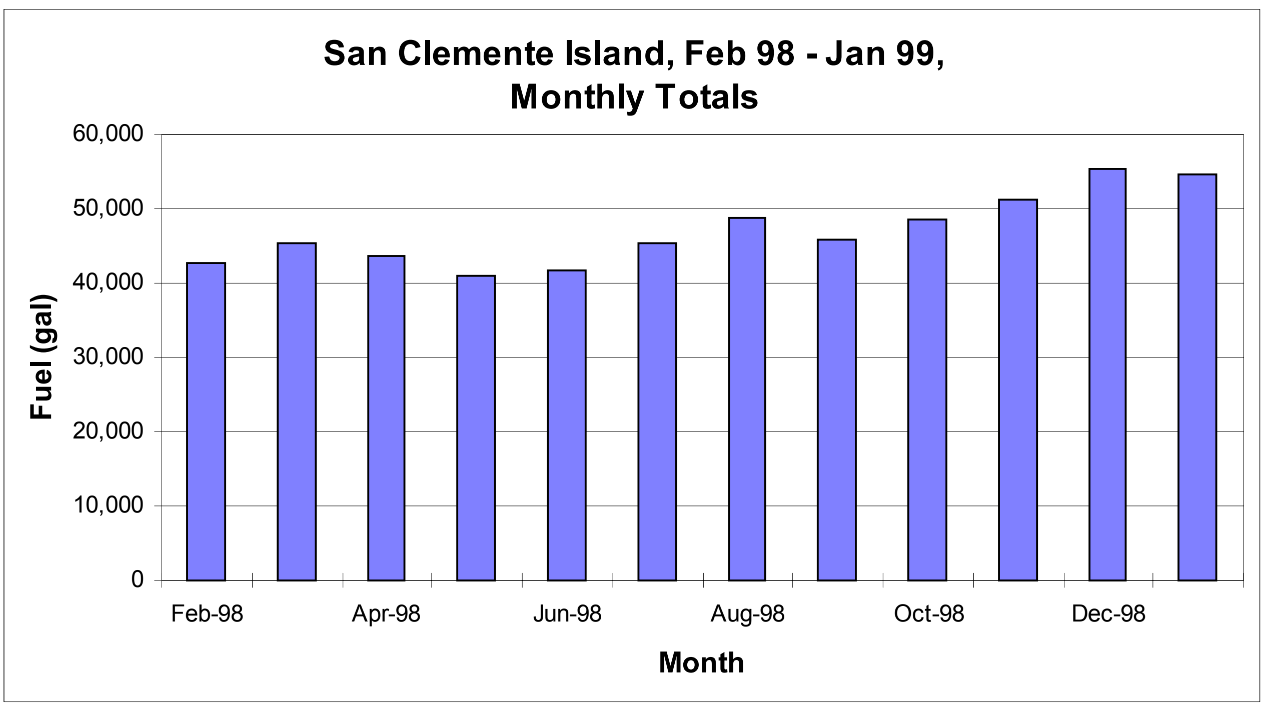

Figure 6: SCI Annual Fuel Consumption Record

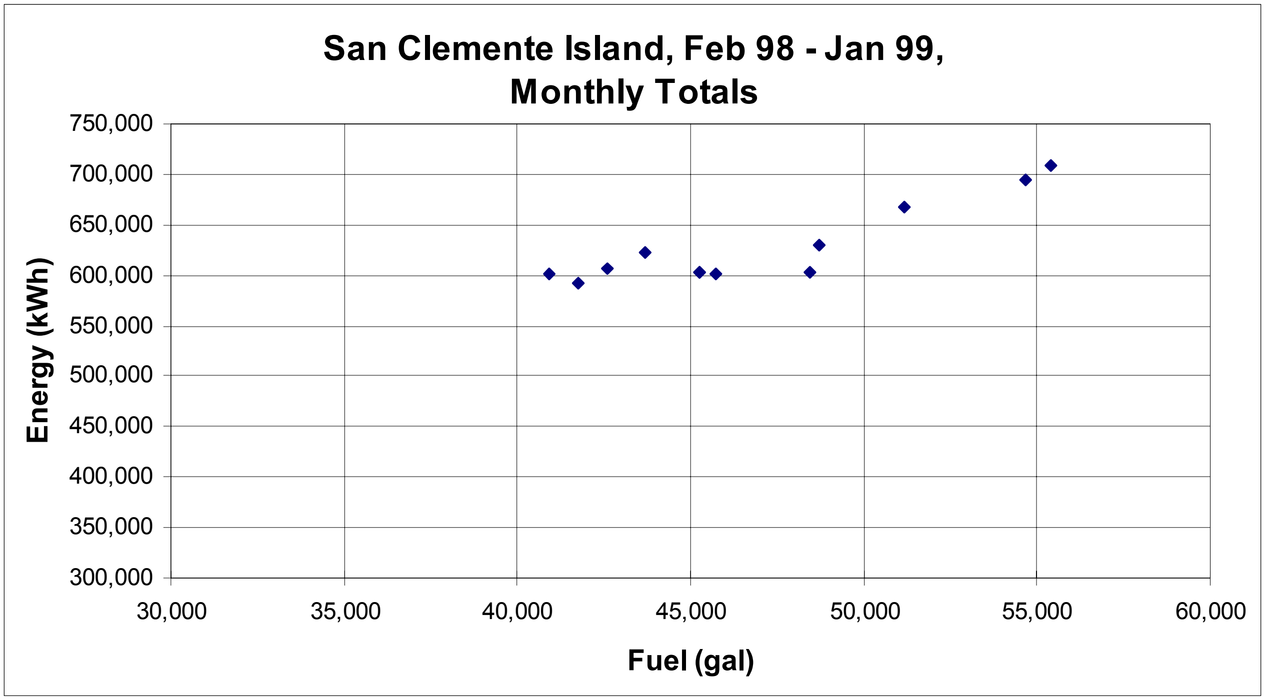

Figure 7: SCI Energy Production vs Fuel Consumption

2.4 Diesel Energy System

The existing SCI power plant consists of four diesel generators. The diesel generator plant is located in a sheltered cove about 3.2 km (2 mi) from the hill where the wind turbines are located. Power for the island grid is generated by diesel generators at 4,160 V and stepped up through two 2,000 KVA transformers to 12,470 VAC, three-phase, three-wire (Delta) for distribution on the island.

- The existing power plant and island power grid has the following electrical characteristics:
- Grid Voltage: 12.470 kV
- Frequency: 60 Hz +/- 1.0 Hz (1998 PIE-NREL Data Record)
- Power Factor: 0.8 – 0.95 lagging
- Average Load 846 kW (1998 SCI Data)
- Maximum Load 1350 kW (1998 SCI Data)
- Minimum Load 500 kW (1998 SCI Data)

Diesel Generator Sets: Electrical power at SCI is presently supplied by four Navy-owned, 3-phase, 4160 V, diesel driven electric generators that are operated by the Public Works Center located at San Diego. The diesel plant on the island was rebuilt in 1994 as Building 60137. The SCI operating data for 1998 shows an average diesel fuel consumption rate of 236.8 l/h (62.6 gph), and average energy conversion rate of 3.2 kWh/l (12.1 kWh/gal, from Table 1). The engines' specific diesel fuel rates are shown in Table 2.

Table 2: Diesel / Generator Power Rating and Fuel Consumption

Manufacturer & Model		Power Rating	Fuel Usage Full Load
Diesel	Generator	kW	l/hr (gal/hr)
1. EMD 8-645E1	KATO (A258730000, 720 rpm)	500	144 (38)
2. EMD 8-645E1	KATO (A258730000, 720 rpm)	500	144 (38)
3. EMD 12-645E4	KATO (A257780001, 720 rpm)	1,200	329 (87)
4. EMD 12-645E1	KATO (A258710000, 720 rpm)	750	216 (57)

Unfortunately, there is little real data for the units operating at no load. The only information available is from EMD Power Products for its similar 12-cylinder, turbo-charged units during EMD factory testing. On units similar to 12-645E4, they recorded 57 liters per hour (15 gal per hour) at rated speed, no load. Based on this information, the hybrid system analysis presented later in this report uses a no-load consumption value of 17% of full load consumption. The other units probably would have no-load rates of 25% of full load, but the hybrid system model uses 17% because the turbo-charged unit is on the majority of the time.

In the current operating protocol, online diesel capacity typically exceeds average demand by a substantial margin to ensure enough capacity to cover excursions and to avoid too frequent switching between diesels. The resulting excess margin causes the diesels to run below their ratings most of the time, resulting in lower energy conversion efficiency. A tighter margin would allow more efficient operation but the more frequent switching would cause faster wear on the diesels and more work for the operators.

Fuel Supply System: Petroleum products are delivered to SCI by regularly scheduled barge and unloaded at Wilson Cove. Diesel fuel (DL-2) is delivered by barge to the fuel tank farm at the north end of Wilson Cove. Barges dispensing fuel tie up to a buoy and pump fuel directly into above-ground storage tanks. The DL-2 fuel is stored in the 37,854 liter (10,000 gal) above-ground tank located to the north of the power plant, Building 60137. Fuel is continuously circulated and centrifuged in this tank. Upon demand, fuel is automatically diverted from returning to the main storage tank and sent to day tanks located just outside the power plant instead. From the day tanks (one for each engine), fuel flows by gravity to each operating engine's fuel pump.

A 757 liter (200 gal) lubrication oil tank is located within Building 60137. Oil is added to each running engine via pumps or centrifuge. Each engine has a direct pipe connection to the lube oil centrifuge, and oil can be gravity-fed at this point or pumped in with pump 7.

The plant is also provided with a waste-oil collection system. This system consists of one 1514 liter (400 gal) holding tank. The tank and pumps are located immediately outside the power plant and are equipped with secondary containment and interconnecting piping.

Balance of Plant: The plant is operated 24 hours per day. Operators observe equipment operation, make hourly log entries, and start and stop the generators as required. The control room has been recently upgraded and is enclosed by sound-reducing insulation and double doors leading to the engine room.

The station auxiliary equipment includes two150 kVA, three-phase, 4160-120/208-V station service transformer, a 120/208-V distribution panel board, a 20-battery 125-V DC station battery bank, and two 2,000-kVA, three-phase, grounded-wye-delta-connected grounding transformers. There is one grounding transformer for each bus in the switchgear to provide a neutral for single-phase, 2400 V-loads.

The power plant switchgear, installed in 1994, has two buses with a vacuum circuit-breaker tie. The circuit-breaker tie will trip automatically in the event of a fault on either bus.

In addition to the 4160-V generators, local emergency generators provide back-up power for critical loads. The power is generated at utilization voltage (120/208V or 480V) and is applied to the load through manual or automatic transfer switches.

Distribution: Electricity is distributed throughout the island by three 12.4-kVA, 4160-V feeders. Feeder # D-Line serves most of the southern end of the island. Feeder # C-Line serves the north-central area of the island, including personnel living facilities, administration and recreational facilities, and the public works buildings. Feeder # A-Line serves the air terminal and associated hangars and maintenance facilities, and loads in the northwest part of the island.

The SCI Air Field portion of the distribution (feeder # A-Line from pad A- 57-7) is completely underground. Feeders # C-Line and # D-Line use mostly overhead lines, consisting of wood poles supporting bare copper conductors.

2.5 Wind Energy Site Description

The wind energy site is located along Telemetry Road in its north-central portion (33° 59 N, 118° 53 W), as shown in Figures 8 and 9. The highest elevation at this location is 222 m (730 ft).

The SERDP site is surrounded by, and dominated by, open, undeveloped habitats. The older wind farm that consisted of six Jacobs 20-kW wind turbines is presently shut-down. It will be removed in 1999. It was constructed in 1987, and is positioned approximately 400 m (1312 ft) to the north of the current wind site at a lower elevation. Telemetry Road runs East-West through the wind site and a Navy building is located roughly 300 m (985 ft) to the south.

There are no trees or other wind obstructions on the site, just light vegetation including grasses and cacti. Several low water tanks and buildings, including the Power Plant Island Utilities, are located to the north and on lower elevations from the wind turbine site. The nearness of the power plant minimizes power line distances to the wind energy site.

This site has moderate winds throughout the year. Although more optimal wind site locations exist on the southern section of the island at higher elevations, this particular site was selected because it does not interfere with radar, communications, or other naval operations. It is close to the San

Clemente Island power plant (approximately 4.3 km or 2 mi), and it does not pose environmental or anthropologic constraints or interfere with Naval Weapons Testing Operations.

Figure 8: SCI Naval Facilities and SERDP Wind Farm Site
Source: USN NFESC Aerial Photograph

Figure 9: Aerial View of SCI Wind Farm
Source: USN NFESC Aerial Photograph

2.6 Wind Energy System

The wind turbine electrical power generation facility is composed of two NEG Micon Model 700-225/40 wind turbines, now called the NM 225/30 model following the merger of Nordtank Energy Group and Micon. Shown in Figure 10, this wind turbine has a rotor area of approximately 700 square meters and a rated output of 225 kW. (The new "30" designation in the model name of the turbine reflects the approximate diameter of the rotor measured in meters, instead of the lower generator rating). The wind turbines start producing power at approximately 4m/s (9 mph) and continue producing power up to 25 m/s (56 mph).

Turbine #1 is located at 32° 59.147 N by 118° 33.127 W, Turbine #2 is located at 32° 59.211 N by 118° 33.072 W and Turbine #3 will be located nearby, all at 223 m (730 ft) altitude. The third 225-kW wind turbine is under construction as this report is being written.

Nacelle: The base frame is designed as a self supporting, integrated welded steel plate construction which also supports the main shaft bearing, gearbox, generator, yaw system, rotor, etc. The integrated construction is hot-dip galvanized and makes up the bottom half of the nacelle cover. The upper half is made from lighter, hot-dip galvanized steel plate.

Yaw System: The yaw system applies forced yaw by electrical gear drive over a cogged ball bearing ring with friction brake system.

Rotor: The rotor consists of three blades manufactured by LM, type LM 13.4, fastened to a hub. The blade diameter is 29.6 m (97.1 ft) with a swept area of 688 m^2 (7407 ft^2). The height to the blade tip in straight upright vertical position is 44.8 m (147.0 ft).

Tower: The tower height is 28.7 m (94.2 ft), with a hub height at the center of the rotor of 30.0 m (98.4 ft). The tower weight is approximately 12,000 kg (26,455 lbm), and has three layers of zinc silicate for protection from the island's marine environment. (An alternative standard tower height for this turbine model provides a hub height of 36.0 m (118.1 ft), and is recommended for sites with a wind shear coefficient higher than 0.1.)

Wind Turbine Control: The main wind turbine control panel is located inside the tower bottom, protected against weather and unauthorized access. Its function is to provide automatic cut-in of the generator to the SCI electrical grid and fault detection and wind turbine protection. This control panel has easy access to operate and control the wind turbine. This controller has displays with fault indicators to secure quick fault finding in case of a turbine stop condition. If the SCI grid fails, and then is brought back on line the wind turbines can be automatically re-started. These wind turbine controllers are under the supervision of the main wind turbine control computer located at the SCI PWC diesel power plant.

Electrical: The MICON wind turbine is equipped with phase compensation which improves the power factor to 0.96 lagging. Over-voltage protection in case of lighting is provided in the control system. Soft cut-in is also provided by thyristors that limit the in-rush current to 1.3 times normal current.

Figure 10: SCI SERDP-Funded NM 225-30 (225 kW) Wind Turbines
Source: USN NFESC Photograph

3.0 THE WIND RESOURCE

3.1 Wind Data Collection and Analysis

In July 1994, the National Renewable Energy Laboratory (NREL) entered into a cooperative agreement with the Naval Facilities Engineering Service Center (NFESC) to collect one full year of high quality wind energy resource data at San Clemente Island (SCI) old Jacobs wind turbine facility, (Tower #6) at 18.3-m (60-ft) height. Three additional UNR-ROHN 43-m (140-ft) towers were installed by NREL crews at SCI sites Met2: 32° 59.236N by 118° 33.209W (at the present 450 kW wind turbine site), Met3: 32° 58.630N by 118° 33.977W (approximately 1 mile south of Met2), and Met4: 33° 01.248N by 118° 33.041W (Lemon Tank Reservoir). We examined the Met2 data in detail, and reviewed historical summary data to describe long-term wind characteristics.

The new data were collected through a full wind-energy meteorological sensor system including two anemometers, two wind vanes, a temperature probe, and a barometric pressure sensor. The anemometers were mounted 24.4-m (80-ft) and 42.7-m (140-ft) high at the new wind energy site on tower Met2.

Data collection began in August 1995, and continued through January 1999. All data was sampled at 1 Hz and then stored as 10-minute and 24-hour averages. The 10-minute average data was used for this report. Annual records of the 10-minute average wind speed, and the monthly records use daily averages. An annual record is derived for air density using

$$\rho = p / (R*T)$$

where ρ is density, p is pressure, T is temperature, and R = 0.286 kJ/(kg*K) for air. Then wind power density is derived using

$$P / A = 0.5 * \rho * V^3$$

where P is power, A is area, and V is wind speed. Using hourly average data, the diurnal wind speeds are created by computing an average for each hour of the day over all days in the period.

Wind direction data is difficult to present because the most common directions do not necessarily have the strongest winds. Therefore, this report includes three types of wind roses: percent time at each direction, average wind speed at each direction, and time-weighted average wind speed at each direction.

3.2 Historical Wind Data

This section begins with a review of 19 years of wind-speed data (1960-1978) at SCI station number 93117, compiled by Pacific Northwest Laboratories and archived by the National Climatic Data Center [2]. Historical annual average wind speeds follow in Figure 11.

The airfield began its operations in 1960 and the historical 19-year anemometer locations changed several times for this collection of historical wind data, and used different sensors, mountings, heights, exposures, and possibly drifting calibrations. Readings on the historical data were made 24 times a day after the first 3-years, which were read 5 to 11 times a day. The heights varied from 5.2 m to 7.9 m, so each year's data were adjusted to the wind turbine hub height [30.0 m (98.4 ft)] using the 1/7 power law. These low measurement heights are very susceptible to the effects of obstructions.

The average 19-year wind speed at SCI adjusted to the 30.0 m (98.4 ft) height is 4.0 m/s (7.8 knots) based on annual averages of hourly data, and the average of the annual standard deviations is 2.6 m/s (5.1 knots). The standard deviation of the annual averages is 0.7 m/s (1.3 knots), giving a variability of 0.7 / 4.0 = 0.175, or 17.5%. Although confidence in the average wind speed is low, this variability implies that the annual average wind speed will fall within +/- 53% (3 standard deviations) 99% of the time, assuming these values are normally distributed.

Some bias toward lower wind speed measurements is expected because of low heights, proximity to buildings and other obstructions, and possible binding (bearing or shaft roughness) of older anemometers. The airfield's altitude is 55.5 m (182ft). The ASR-8 Radar hill with an east-west ridge peaking at 160 m (524 ft) south of the airfield is approximately 2,300 m (7,500 ft) away. Although the ridge does not shadow the prevailing north to northwest winds, it can deflect them upward and cause lower measurements below. Winds from the northeast to southwest are sheltered. Because these factors are not tractable, no attempt is made to adjust the data to account for them. However, the averages found here are not used for the hybrid system modeling later in this report, but the interannual variability of 17.5% is used for the sensitivity analysis.

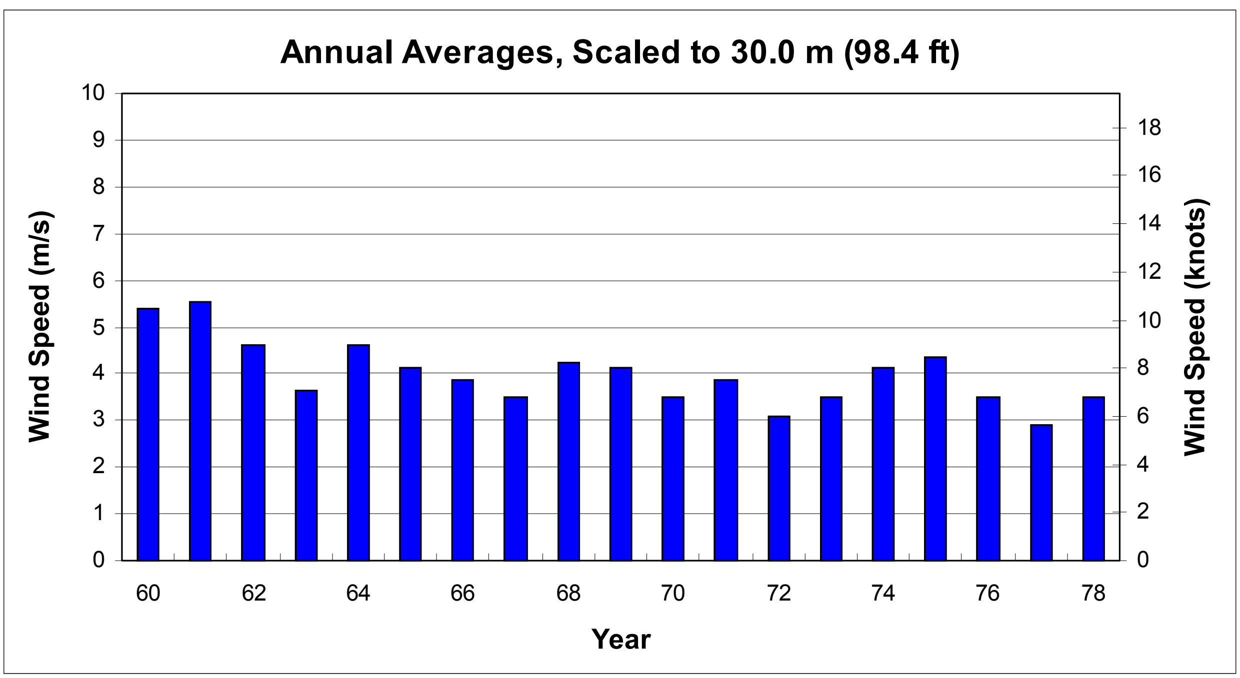

Figure 11: SCI Historical Wind Speeds

The following figures, 12 and 13, show some average diurnals from 1983-4 and 1984-5 collected at the old Jacobs site [3]. The data was collected with a MAXIM type 40 anemometer at 32 ft elevation and a Second Wind Datalogger Model A1-2002-4K. The average wind speed for both years at this site was 6.1 m/s (13.6 mph) at 9.8 m (32 ft) height, which would indicate a speed of 7.2 m/s (16.0 mph) at 30.5 m (100 ft) using the 1/7 power law.

	Wind Speed (mph) at												Avg	Diurnal
Year	0000	0200	0400	0600	0800	1000	1200	1400	1600	1800	2000	2200	WS	Swing
1983	0200	0400	0600	0800	1000	1200	1400	1600	1800	2000	2200	2400	(mph)	(mph)
Aug	11.6	11.5	10.5	9.4	8.9	10.0	13.5	18.0	19.8	19.6	17.6	13.4	13.7	10.9
Sep	11.5	10.6	10.3	9.1	9.8	11.1	13.6	16.5	18.3	17.9	15.5	12.3	13.0	9.2
Oct	11.9	9.8	9.8	9.5	8.3	8.1	10.0	12.9	15.1	14.5	14.3	12.4	11.4	7.0
Nov	13.6	12.9	12.5	12.0	11.6	12.9	13.4	15.1	16.4	16.1	15.6	15.1	13.9	4.8
Dec	13.5	13.8	12.9	10.6	10.8	12.1	14.4	14.6	13.9	14.3	13.4	12.9	13.1	4.0
1984														
Jan	10.5	10.8	10.3	9.7	8.5	9.5	9.8	11.9	15.1	15.9	15.1	12.1	11.6	7.4
Feb	14.6	13.4	11.6	11.6	11.8	13.0	13.8	15.6	17.6	18.1	16.9	15.5	14.5	6.5
Mar	13.3	12.1	9.8	9.5	11.1	12.3	14.4	17.0	20.4	20.6	18.9	15.9	14.6	11.1
Apr	17.4	14.9	13.6	13.0	13.9	16.8	20.5	24.1	24.4	22.8	20.8	18.9	18.4	11.4
May	12.3	11.5	10.5	9.1	10.3	11.4	14.0	17.8	18.4	19.2	16.8	14.8	13.8	10.1
Jun	11.1	9.4	8.9	8.5	8.6	9.9	11.9	15.9	19.0	18.6	17.0	13.5	12.7	10.5
Jul	13.9	12.5	12.4	10.9	9.9	11.4	17.4	20.8	19.0	17.6	17.8	16.8	15.0	10.9
Avg	13.1	12.0	11.1	10.3	10.4	11.7	13.9	16.6	18.0	17.8	16.6	14.6	13.8	7.6

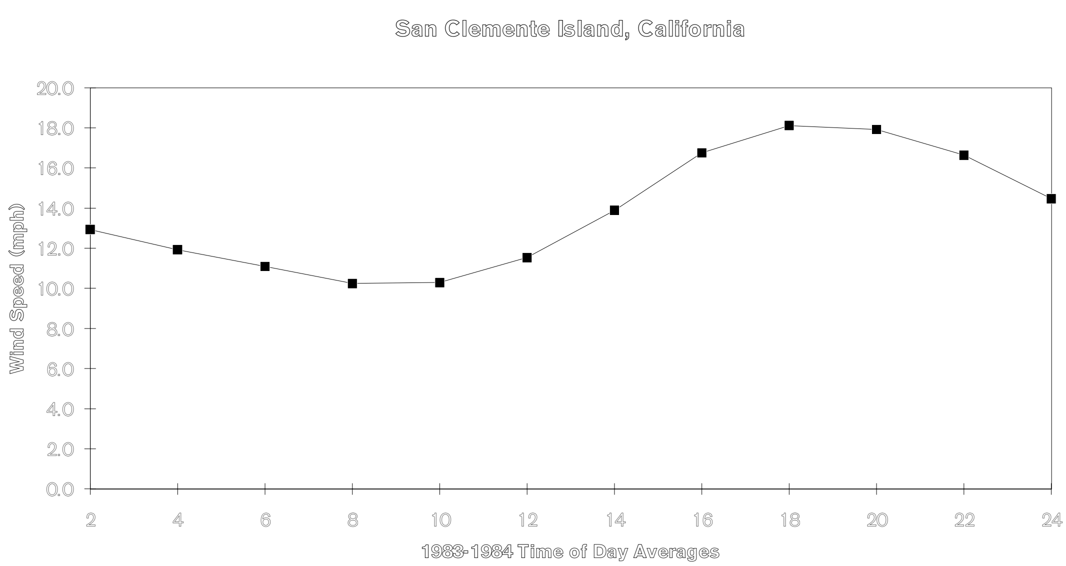

Figure 12: Annual Average Diurnal, Jacobs Site, 1983-4

Year 1984	0000 0200	0200 0400	0400 0600	0600 0800	0800 1000	1000 1200	1200 1400	1400 1600	1600 1800	1800 2000	2000 2200	2200 2400	Avg WS (mph)	Diurnal Swing (mph)
	Wind Speed (mph) at													
Aug	11.4	10.5	9.6	8.6	8.2	10.0	13.2	17.2	19.0	18.2	15.9	12.9	12.9	10.8
Sep	12.5	12.2	11.4	11.2	11.2	11.9	14.4	17.1	18.5	18.4	17.5	15.6	14.3	7.3
Oct	12.8	12.5	11.4	11.2	12.2	13.8	14.5	17.1	19.4	18.9	15.5	12.6	14.3	8.2
Nov	12.1	12.2	11.5	11.2	11.2	12.2	13.8	14.2	14.9	13.6	13.1	13.1	12.8	3.7
Dec	10.8	9.9	10.5	10.9	10.8	11.2	10.8	11.1	13.1	13.1	12.6	11.2	11.3	3.2
1985														
Feb	10.5	10.1	10.1	9.6	9.9	10.8	11.5	13.1	13.0	12.9	12.2	11.9	11.3	3.5
Mar	14.4	13.8	12.9	12.4	12.9	14.2	16.8	18.5	19.6	18.6	16.6	15.1	15.5	7.2
Apr	13.6	11.4	11.1	10.5	10.8	12.4	16.0	17.9	19.4	18.2	15.9	14.2	14.3	8.9
May	12.4	11.8	10.5	9.6	10.8	10.8	13.6	18.4	20.2	18.9	16.2	14.2	14.0	10.6
Jun	10.2	9.6	8.9	8.8	9.0	9.8	12.5	14.4	16.9	17.0	13.5	11.1	11.8	8.2
Jul	13.1	11.6	10.2	10.1	10.1	11.5	14.5	18.1	20.8	21.9	18.4	15.5	14.7	11.8
Avg.	12.2	11.4	10.7	10.4	10.6	11.7	13.8	16.1	17.7	17.2	15.2	13.4	13.4	7.3

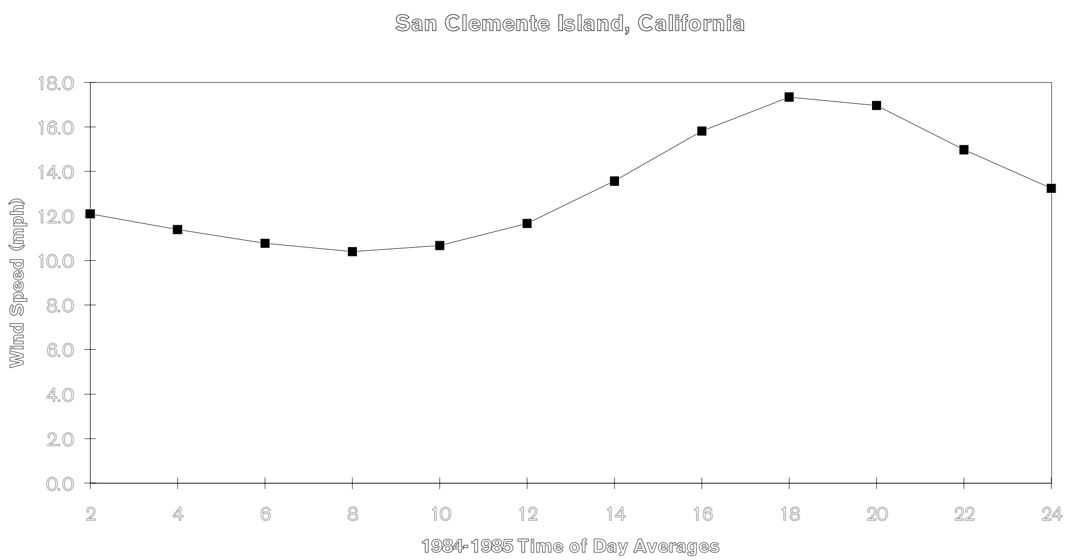

Figure 13: Annual Average Diurnal, Jacobs Site, 1984-5

3.3 Current Wind Data

Data were collected between August 1995 and January 1999 at the 43.6-m (140-ft) meteorological tower number 2 at the designated SCI Wind Turbine Site. The wind speed data was collected at 43.6-m (140-ft) height and temperature and pressure at 3-m (10-ft).

The data collection rate was about 75%, with several gaps spread throughout the data sets. This low collection rate is attributed to a lack of available staff for checking, downloading data, and maintaining the site data acquisition systems. In addition, the data shows error rates of 5 to 10%. Because no year has a full data set, a composite 10-minute data set was created to use for generating a wind speed histogram, annual diurnal, wind rose, and hourly data for hybrid system modeling. Using 1998 as the baseline data set, both missing data and bad data segments were filled in with good data segments from the other years as itemized in Table 3.

Table 3: Source Years for Composite Wind Data Set

Julian Day	Source Year
1-31	1999
32-36	1996
37-238	1998
239-273	1995
274-284	1998
285-287	1995
288-365	1998

Statistical analysis of the last 3-years of daily meteorological data yielded the results shown in Table 4, and a full wind speed distribution is presented in Figure 14. Subsequent hybrid system modeling used the composite data set adjusted to wind turbine hub height. The 10-minute data set was not used here because of the amount of manual processing required to remove bad data segments. However, the 10-minute data would indicate somewhat higher standard deviations of 3.3 m/s and lower minima of 0.0 m/s (both affected by bad data), with maxima reaching 25.9 m/s.

Table 4: Summary of Current SCI Meteorological Data

Channel	Units	Average	Standard Deviation	Minimum	Maximum
Wind Speed, 1996	m/s	6.1	2.7	1.8	16.9
Wind Speed, 1997	m/s	5.5	2.6	1.4	18.0
Wind Speed, 1998	m/s	6.6	2.7	2.3	17.0
Wind Speed, composite	m/s	6.4	2.7	2.3	17.0
Wind Speed, composite	knots	12.4	5.2	4.5	33.0
Ambient Temp, 1998	°C	14.4	2.5	8.2	22.8
Ambient Pressure, 1998	mbar	990	3.3	981	1002
Air Density, 1998	kg/m^3	1.20	0.01	1.17	1.24
Power Density, 1998	W/m^2	267	400	7.6	2990

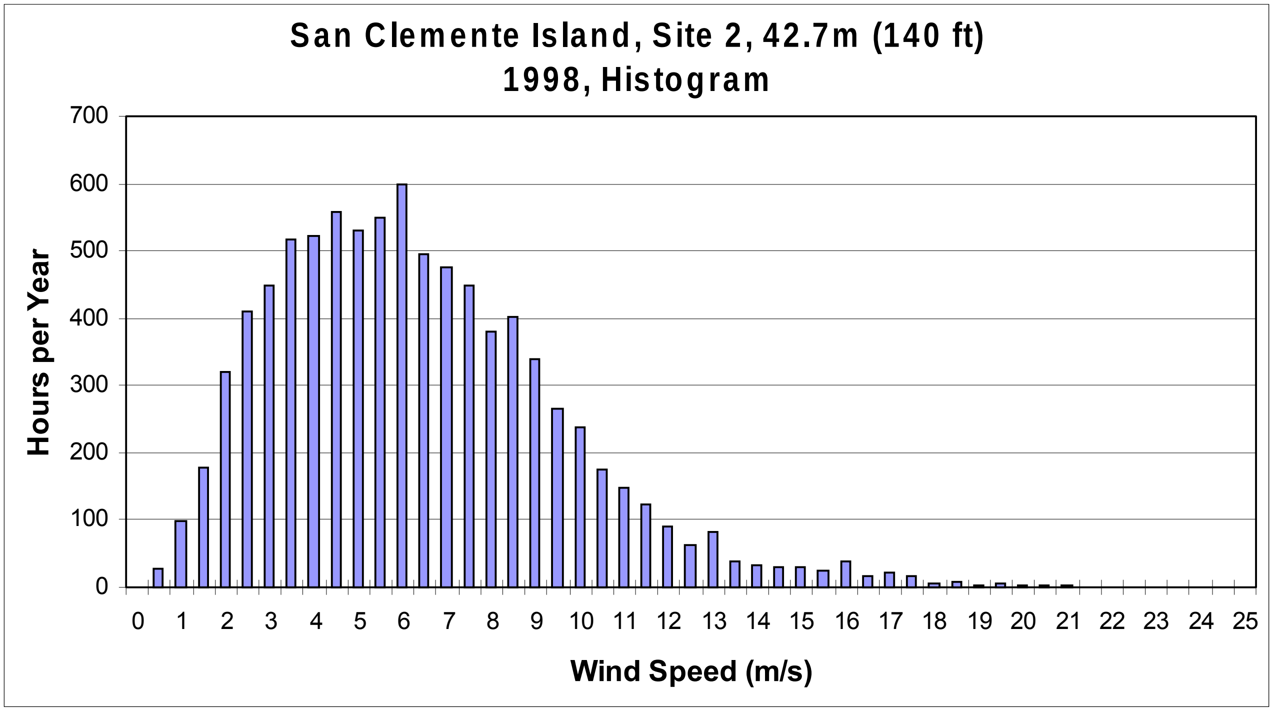

Figure 14: SCI Wind Speed Frequency Distribution

Annual records using monthly averages have been plotted for wind speed, ambient temperature, ambient pressure, air density, and power density. The source data were derived from NREL testing on SCI at 42.7-m (140-ft) on tower Met2 for the August 1995 through January 1999 period. Missing and bad data segments were removed from the daily and monthly-averaged data for these records. Wind-speed records for 1995 through 1999 appear in Figures 15-19, and records for other meteorological parameters in 1998 are shown in Figures 20-23.

Wind speeds are fairly consistent at this site; no months stand out as significantly higher or lower between the 3-years examined. The wind speed range generally falls between 5 and 8 m/s. Temperature and pressure cycle gently with more warmth and lower pressure in the summer, causing slightly lower summer densities. Power density looks like an exaggeration of wind speed, as expected from its cubic relationship.

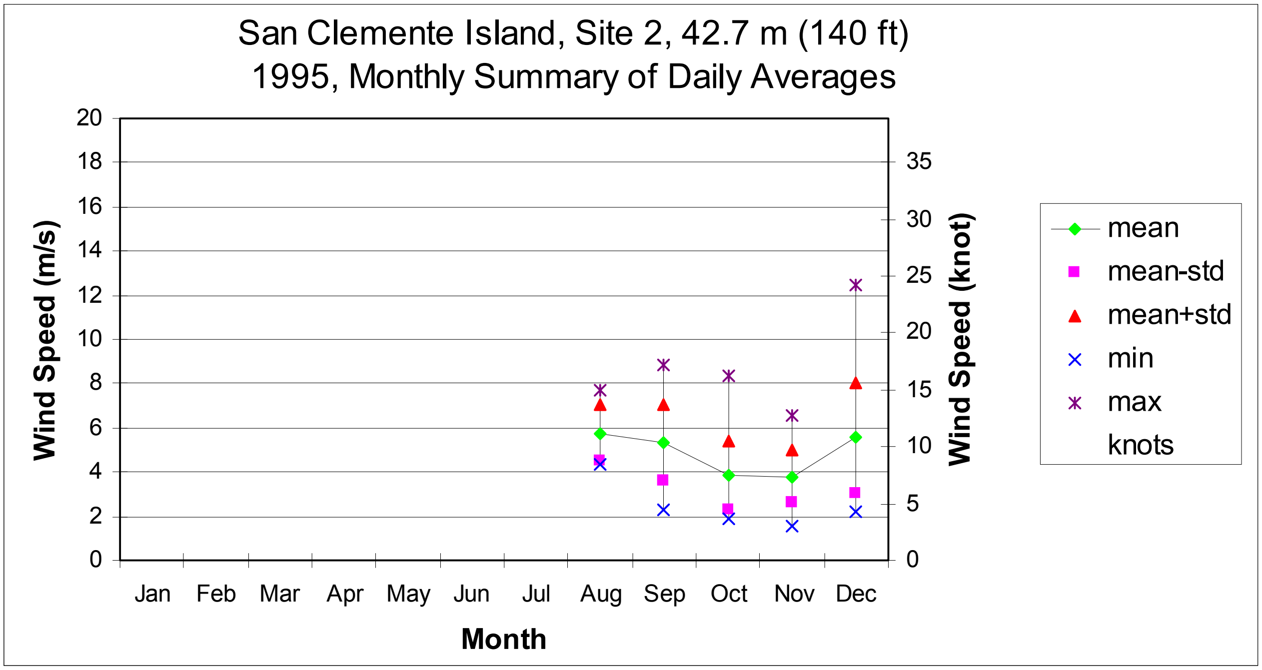

Figure 15: SCI Monthly Averaged Wind Speed, 1995

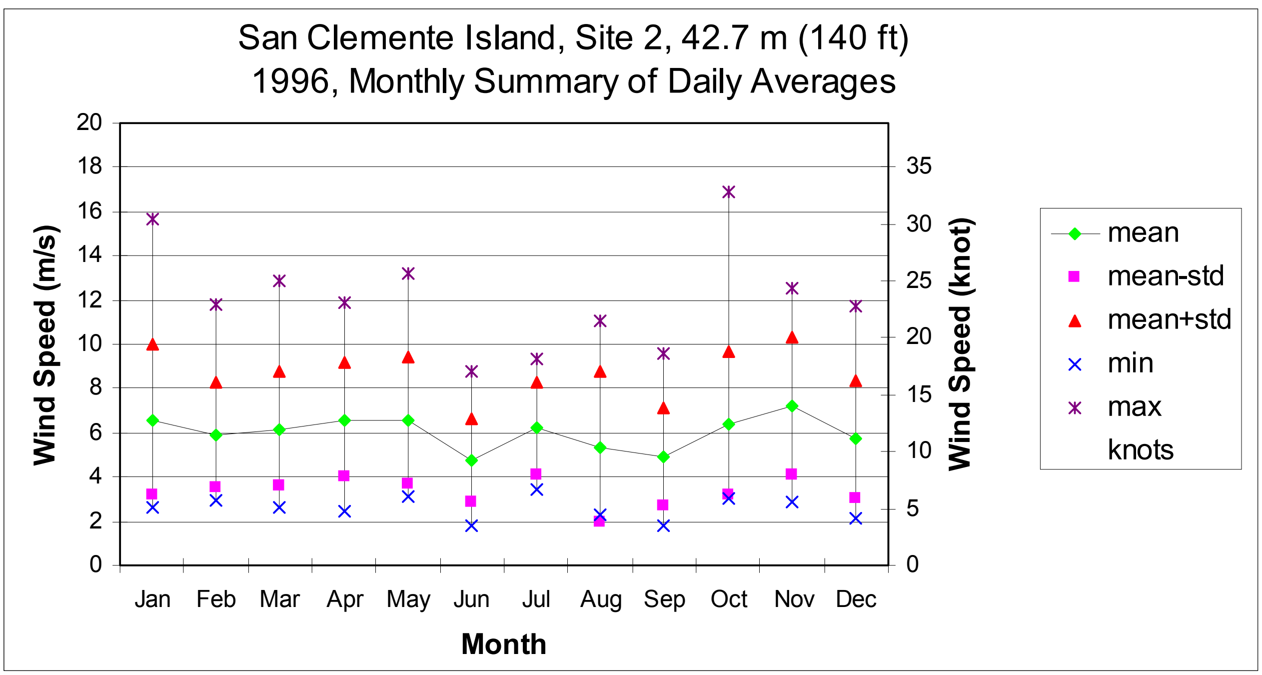

Figure 16: SCI Monthly Averaged Wind Speed, 1996

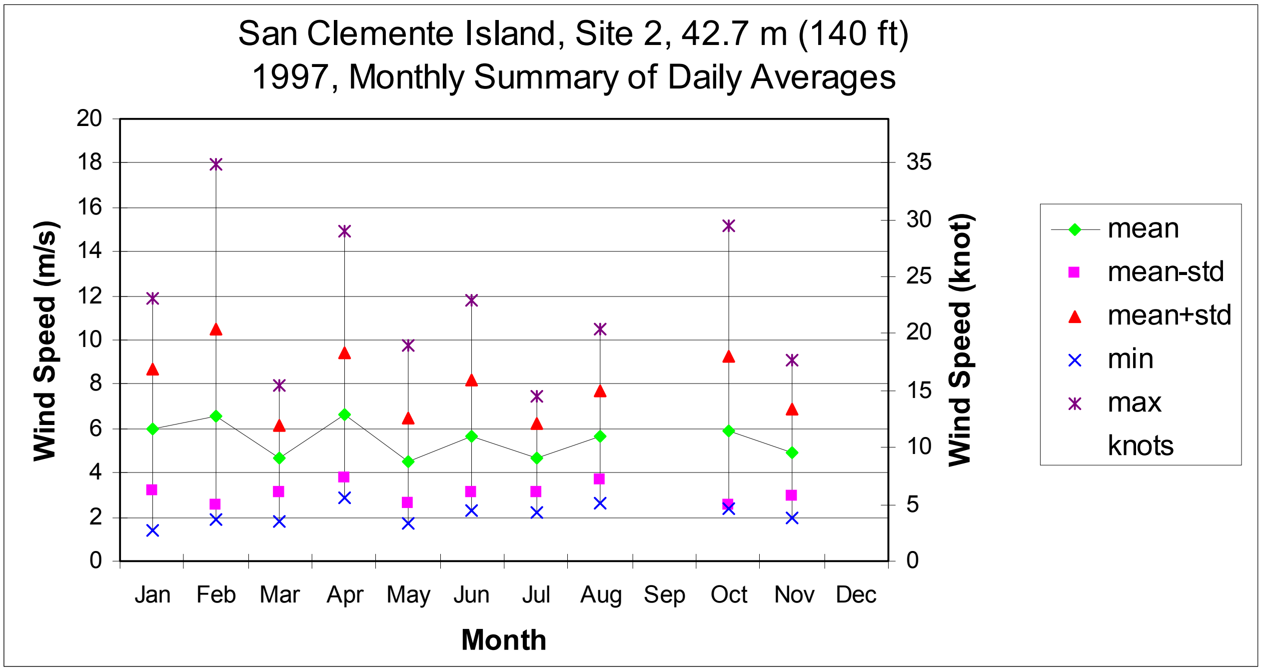

Figure 17: SCI Monthly Averaged Wind Speed, 1997

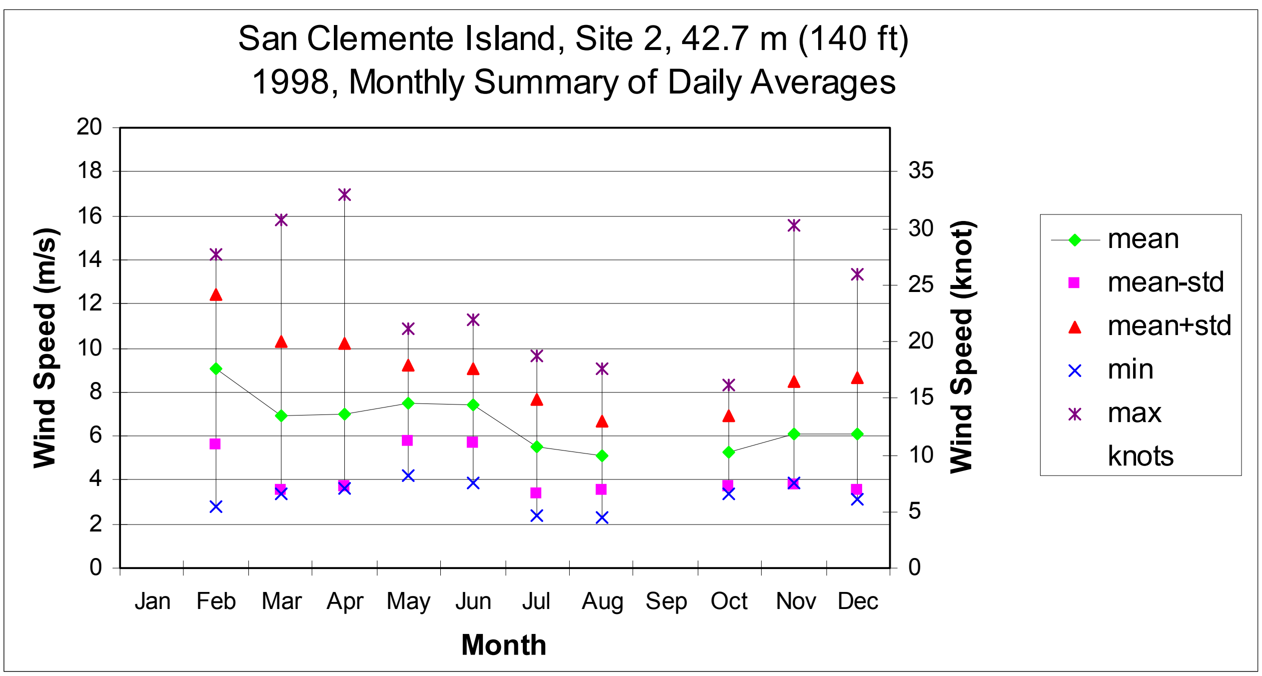

Figure 18: SCI Monthly Averaged Wind Speed, 1998

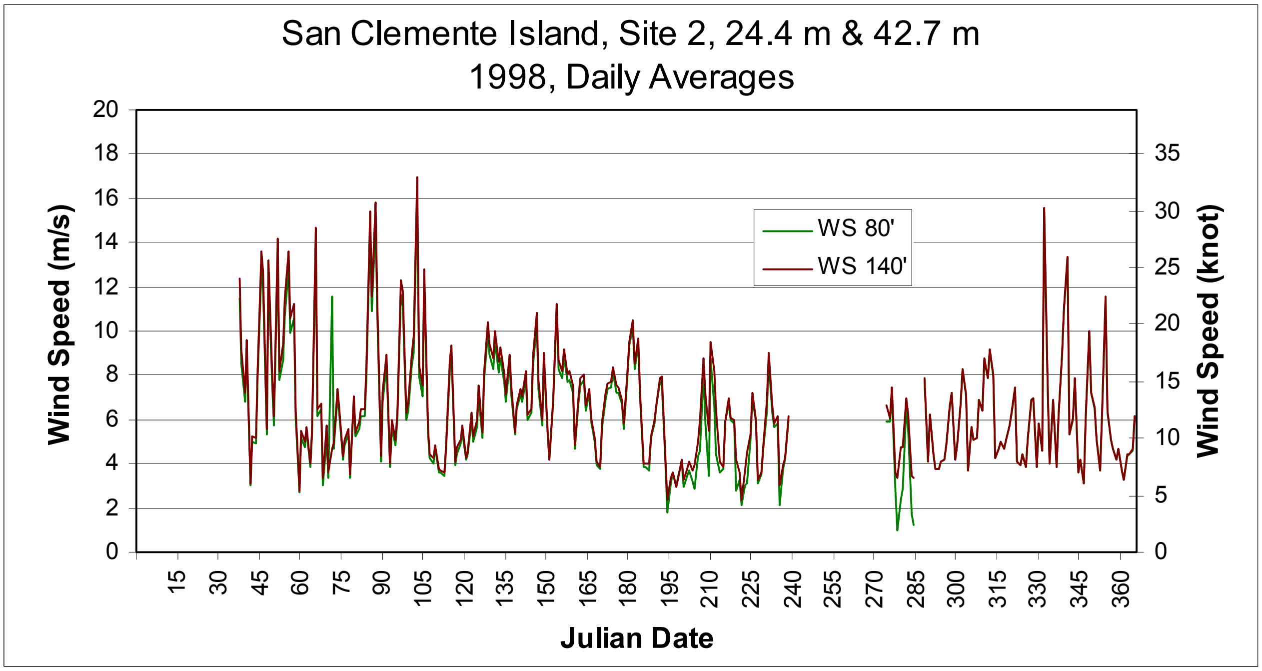

Figure 19: SCI Daily Averaged Wind Speed, 1998

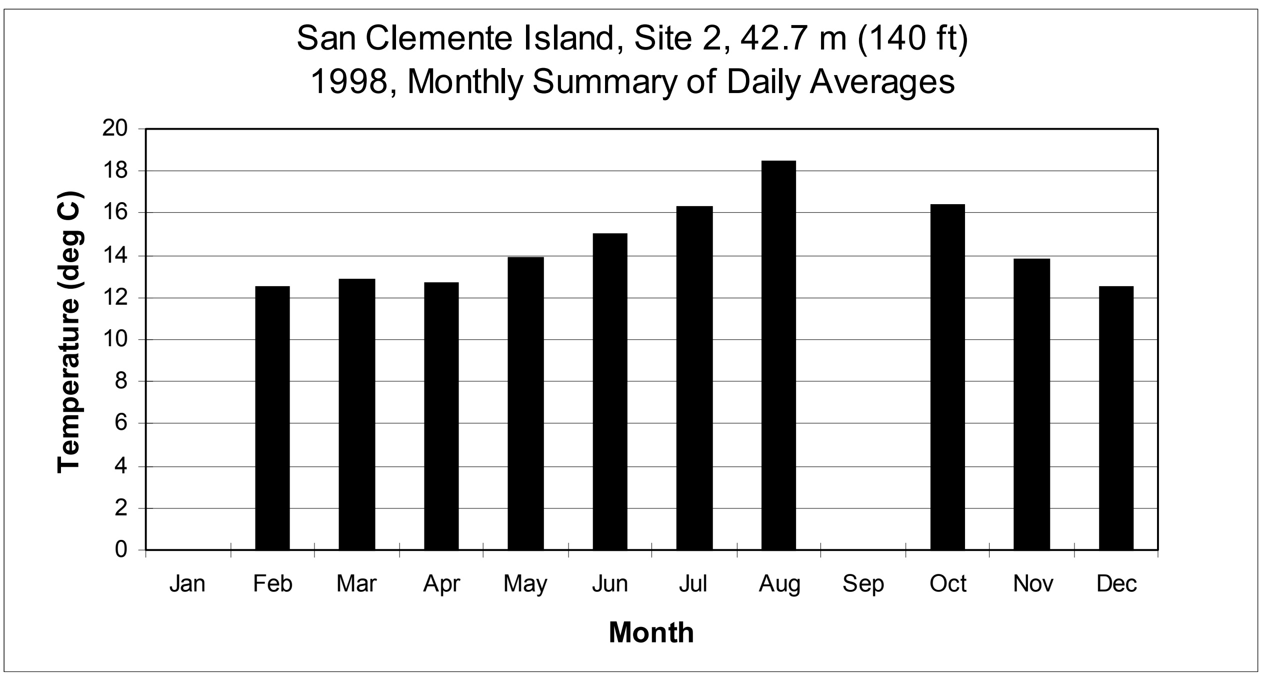

Figure 20: SCI Monthly Averaged Temperature, 1998

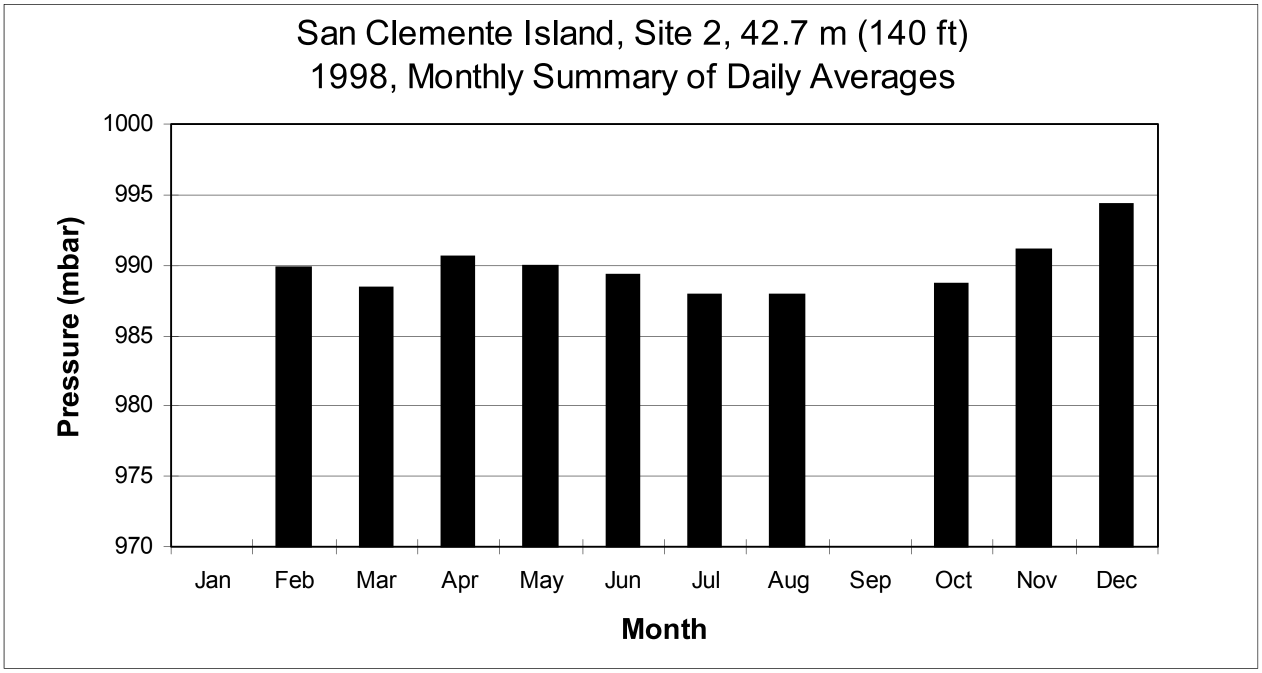

Figure 21: SCI Monthly Averaged Pressure, 1998

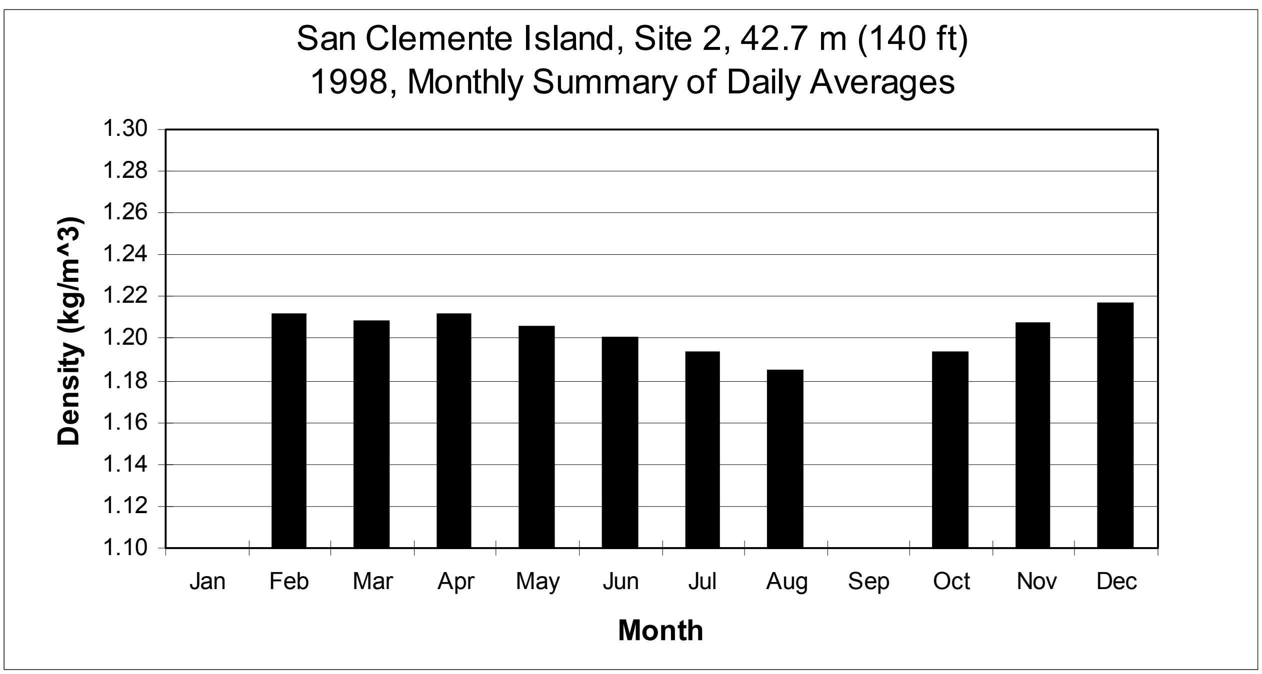

Figure 22: SCI Monthly Averaged Density, 1998

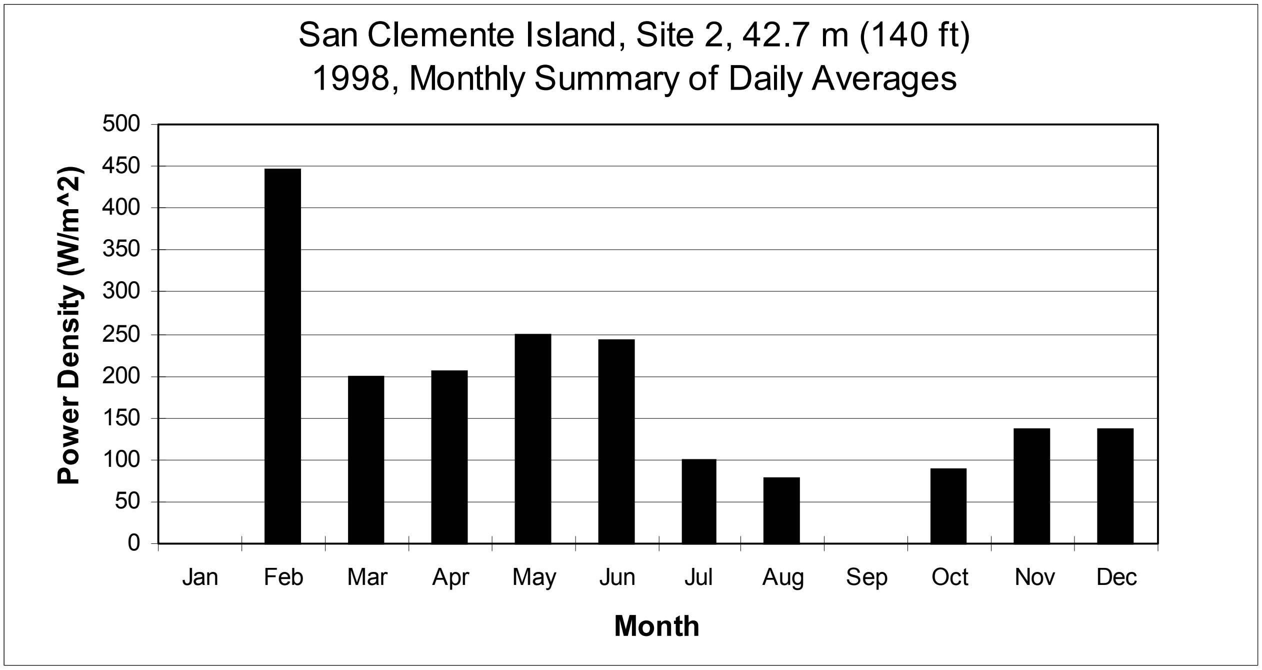

Figure 23: SCI Monthly Averaged Wind Power Density, 1998

The annual average diurnal given in Figure 24 shows a stable pattern, with wind speeds falling between 5 and 7.5 m/s. They are slightly lower through night and morning, and slightly higher through the afternoon and evening. The diurnal is derived from the 1-year composite hourly data set described earlier. Each hour is averaged through the whole year; any specific day could be quite different. For reference, the column labeled "0000" refers to the first hour of the day: 0000 to 0100.

The wind roses shown in Figures 25-29 also use the composite hourly data set. They indicate prevailing winds from the west and west by northwest, with somewhat stronger average wind speeds in these directions as well as in the northwest, southwest, and south.

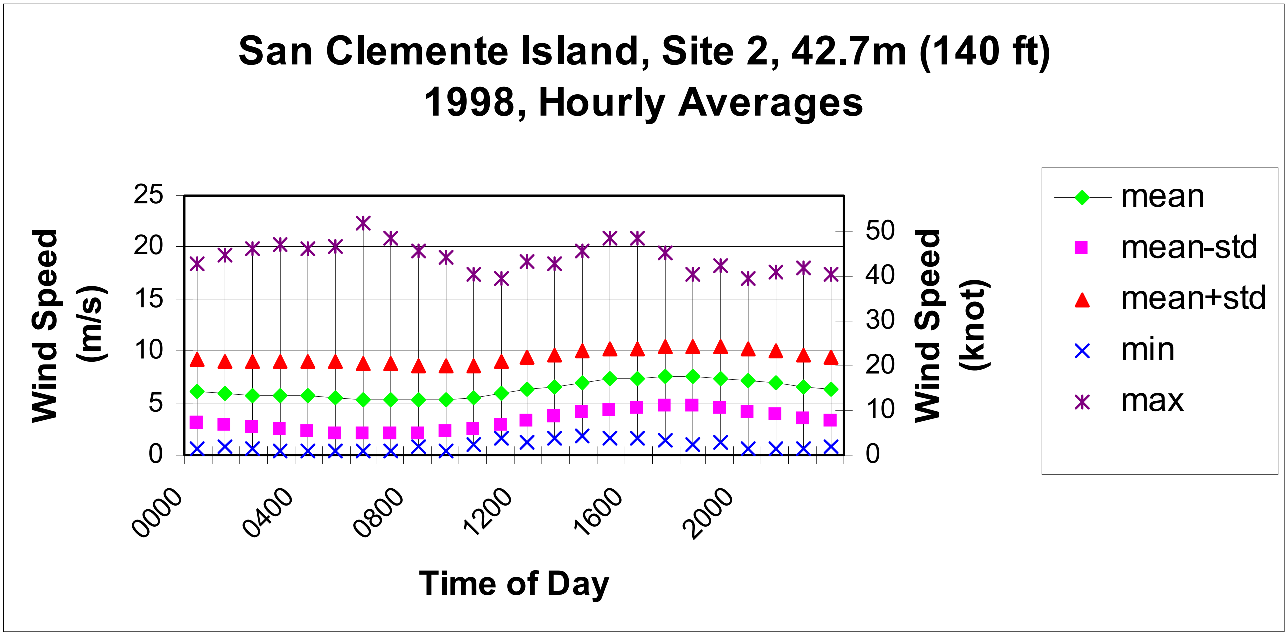

Figure 24: SCI Annual Average Diurnal Wind Speed

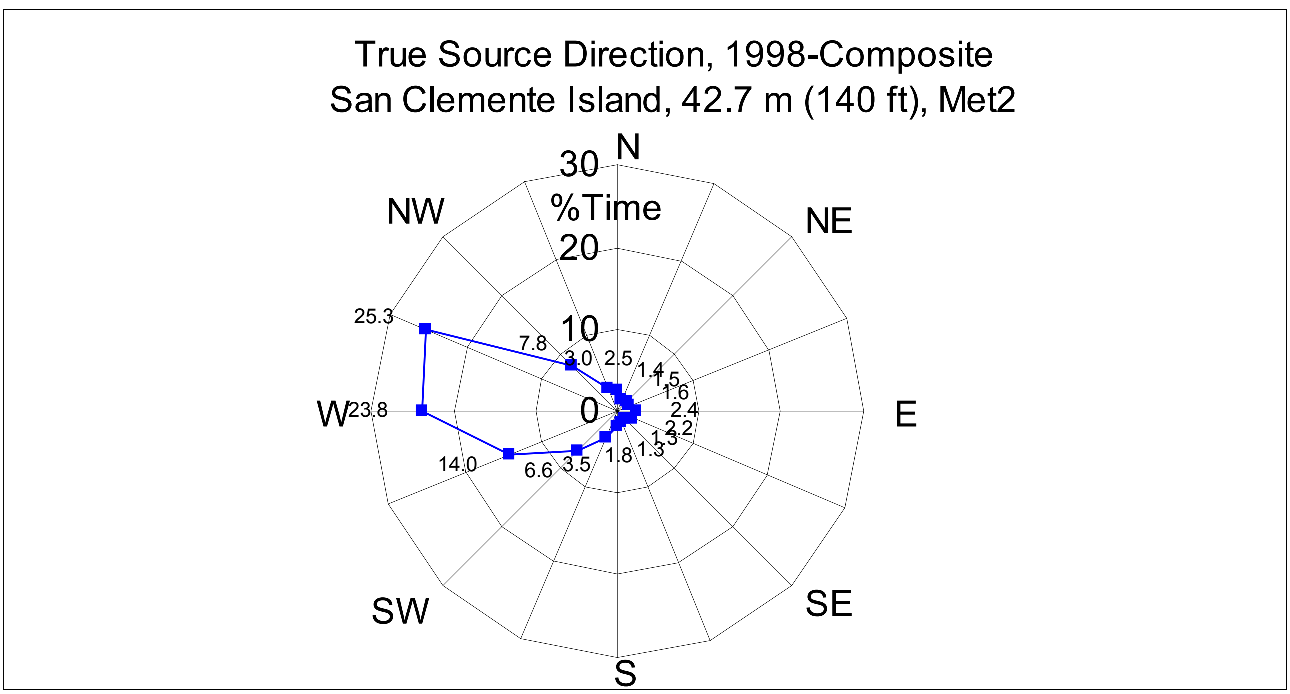

Figure 25: SCI Wind Rose: Percent Time

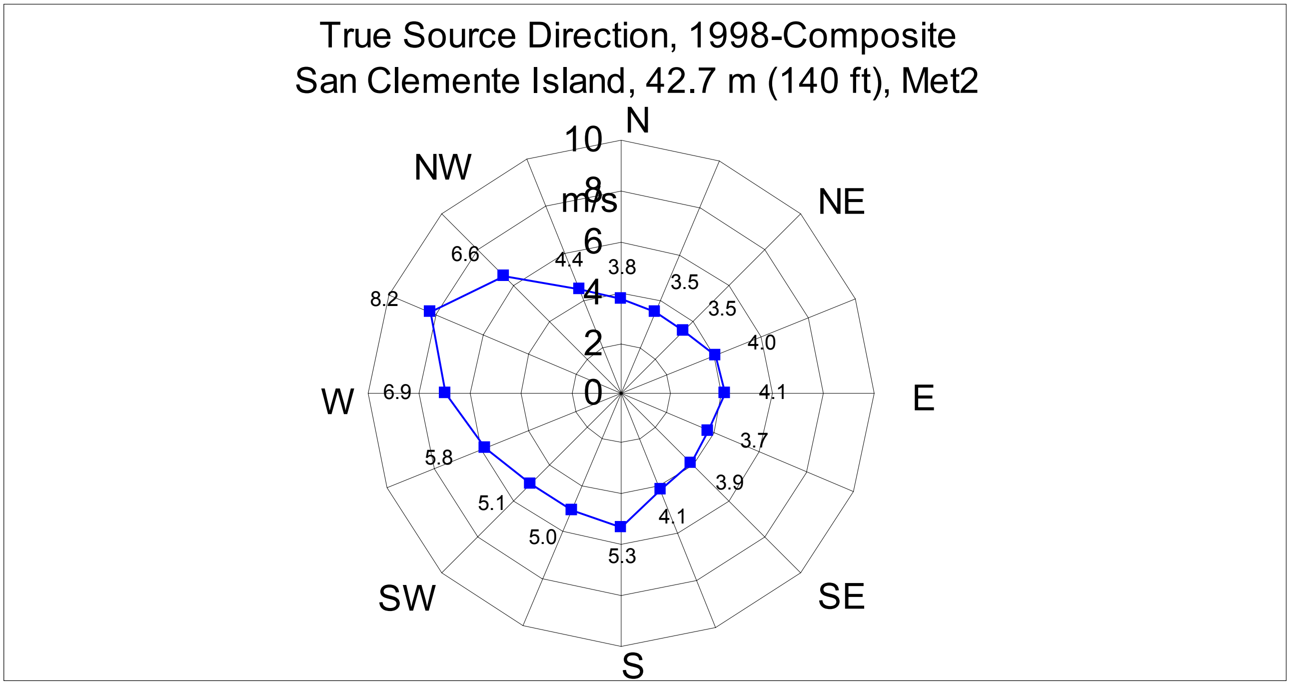

Figure 26: SCI Wind Rose: Average Wind Speed (m/s)

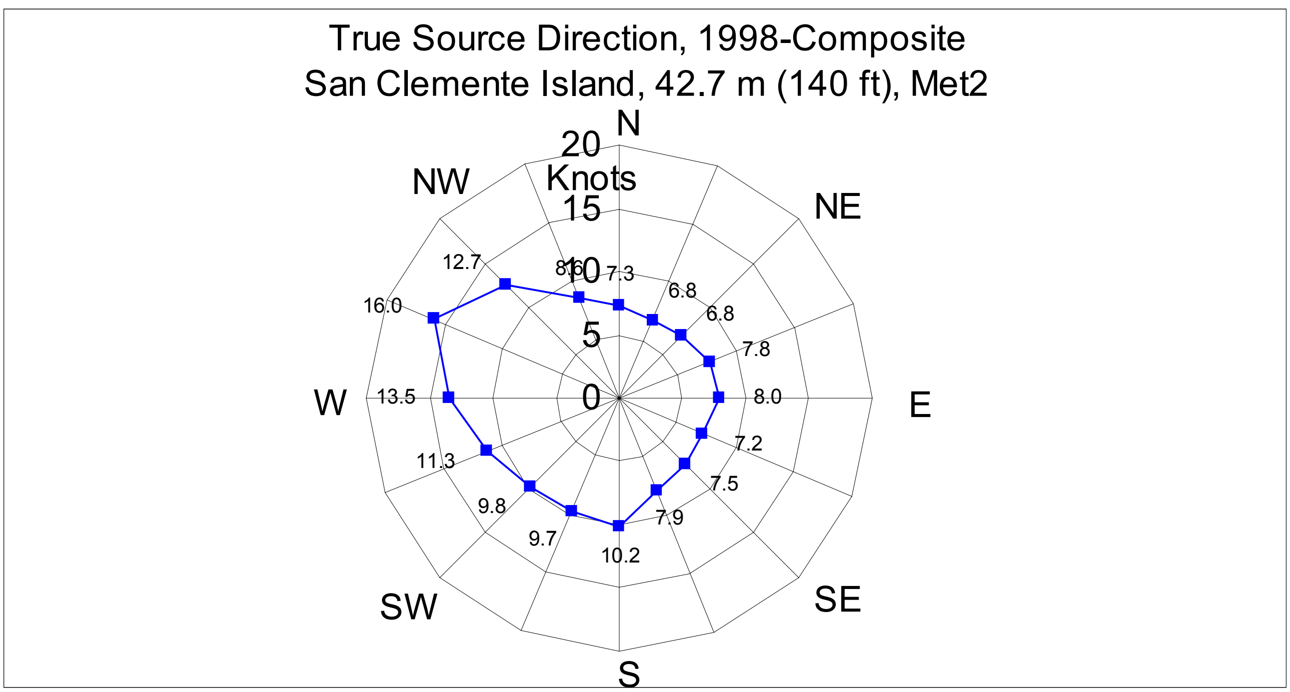

Figure 27: SCI Wind Rose: Average Wind Speed (knots)

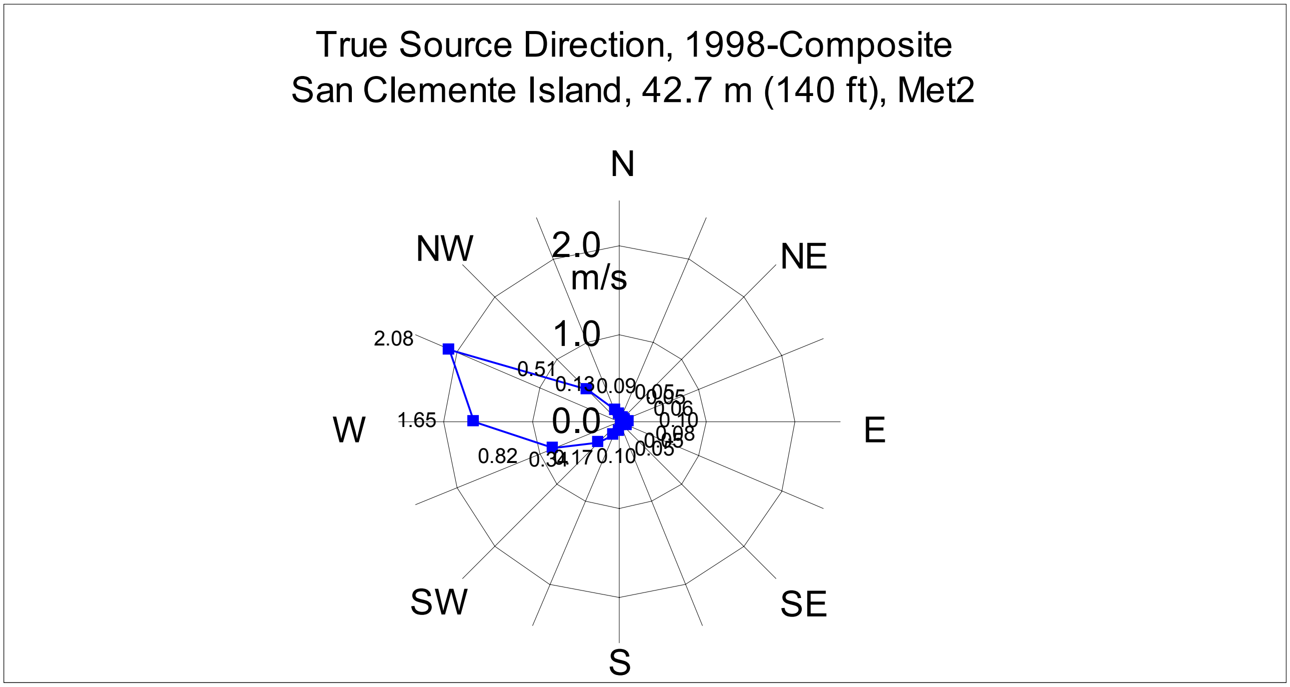

Figure 28: SCI Wind Rose: Time Weighted Average Wind Speed (m/s)

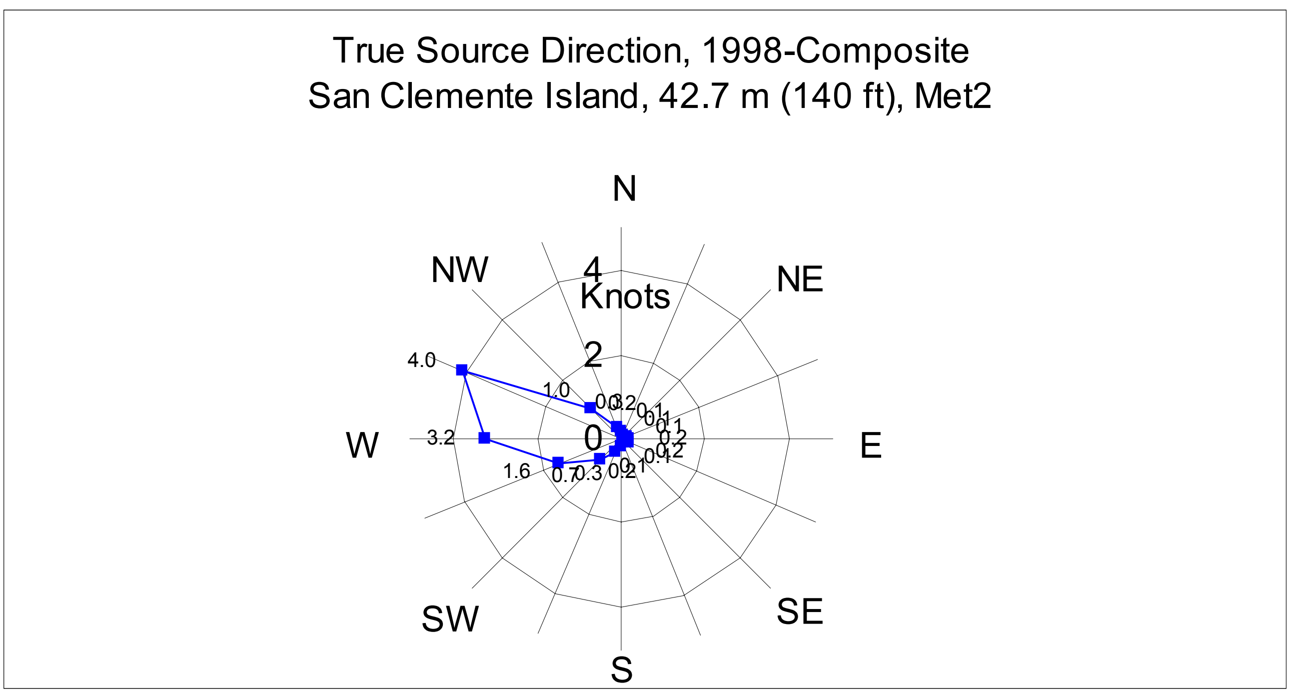

Figure 29: SCI Wind Rose: Time Weighted Average Wind Speed (knots)

4.0 WIND-DIESEL HYBRID ENERGY SYSTEM

The San Clemente Island (SCI) hybrid-energy system, consisting of combined wind and diesel generators is proving to be economically and environmentally advantageous for SCI. A study of such a system was conducted using a spreadsheet program to compare the cost of power generation for the diesel-only baseline to several wind-diesel hybrid cases. The hybrid cases were compared to determine the most cost-effective number of wind turbines.

The wind-diesel hybrid system is relatively simple. Two commercially available wind turbines (total capacity of 450-kW) are combined with the existing 2950-kW diesel generation, a third wind turbine (total wind capacity of 675-kW) will be online July 1, 1999, and a fourth is scheduled for 2001 (total wind capacity of 900-kW). With a demand peak of 1350-kW, no more than 1700-kW of diesel should be necessary at any time. Therefore, wind penetration of "on-line" capacity with two wind turbines is 450/1700 = 26%, and four wind turbines is 900/1700 = 53%. Based on instantaneous power, wind penetration can range from 0 % when there is no wind to 180% when peak wind power of 900-kW is combined with a minimum load of 500-kW.

Several assumptions were made regarding the power that can be generated by the wind. First, at least 200-kW always must be generated by the existing diesel generators, even if there is excess wind capacity. Second, it is assumed that only the necessary number of turbines will generate power at any given time, with the remaining turbines idled.

4.1 Diesel System Operation

As mentioned in Section 2.3, there are four diesel generator sets, two generators rated by the Navy at 500-kW, one at 750-kW, and one at 1200-kW. One generator of each size is included in the hybrid-system model. The generator fuel/energy curves were given in Section 2.3. Typically, only one diesel is run at a time, unless the island's electrical demands require more than 1000-kW. Then two diesels are generally on line to provide the electrical capacity required.

The latest SCI power demand for 1998 ranges from a minimum of 500-kW to a maximum of 1350-kW. The fuel needed (with no wind-energy input) is calculated based on minimizing the number and rating of operating diesel generators. Configuring the diesels to produce 500, 750, 1200, or 1700-kW can meet the power demand.

The diesel generators follow the load automatically through speed and frequency monitoring. The diesels have no specific selection priority, but there are other constraints. At least one diesel must be on line at all times to ensure reliable capacity and system stability; the present minimum operating load for the diesels are set at 200 kW, or 40% rated power for the smallest unit. In the future, this may be set to 100 kW.

Also, according to SCI power system operating data from 1996 to 1998, the manual operating scheme tends to favor running the large engine for long periods of time, as estimated from the Navy-supplied data. That reduces the number of starts. An optimized operating scheme alone could provide significant fuel savings, but it would require many more diesel starts and some form of automated system control.

For this study, the spreadsheet model follows the actual manual operating scheme for all cases, wind and baseline. The hybrid wind-diesel systems likely would show greater savings over the baseline with such an optimizer.

4.2 Wind Turbine Operation

The wind generation system modeled uses between 1 and 4 commercial wind turbines rated at 225-kW each. The sea level power curve for this turbine is shown in Figure 30. A fifth-order polynomial was fit to the curve for use in the spreadsheet model. No density correction was made to the power curve, as the present San Clemente Island wind site is only 700-ft to 750-ft above sea level. The wind turbines can be curtailed (shut down) as necessary when excess wind energy is available.

The net annual energy production (AEP) can be computed by multiplying the power production level by the number of hours for each wind speed level and summing the results. If P_i is power and N_i is number of hours at each wind speed, then:

$$AEP = \text{sum}\,(P_i * N_i), \quad i = 0.0, 0.5, 1.0, \; ... \; 100.0 \text{ m/s.}$$

The actual AEP is often lower because of various system losses. Assessment of the wind site showed that there are not any significant obstructions to the prevailing wind flow. Also, there is room for additional wind turbines without interference, so array losses should be mitigated with proper siting. Other sources of loss could include 1 - 5% availability loss for operation and maintenance, up to 5% for blade soiling losses, up to 2% for turbulence losses, and up to 3% for control, grid, and collection system losses. Using 97% availability, the combination of these sources is significant, having a possible net loss of 11.5%. However, the first year of operation for the two SCI wind turbines has generated power curves that match the manufacturer's published curve. Therefore, no losses have been applied in the energy system model for this report.

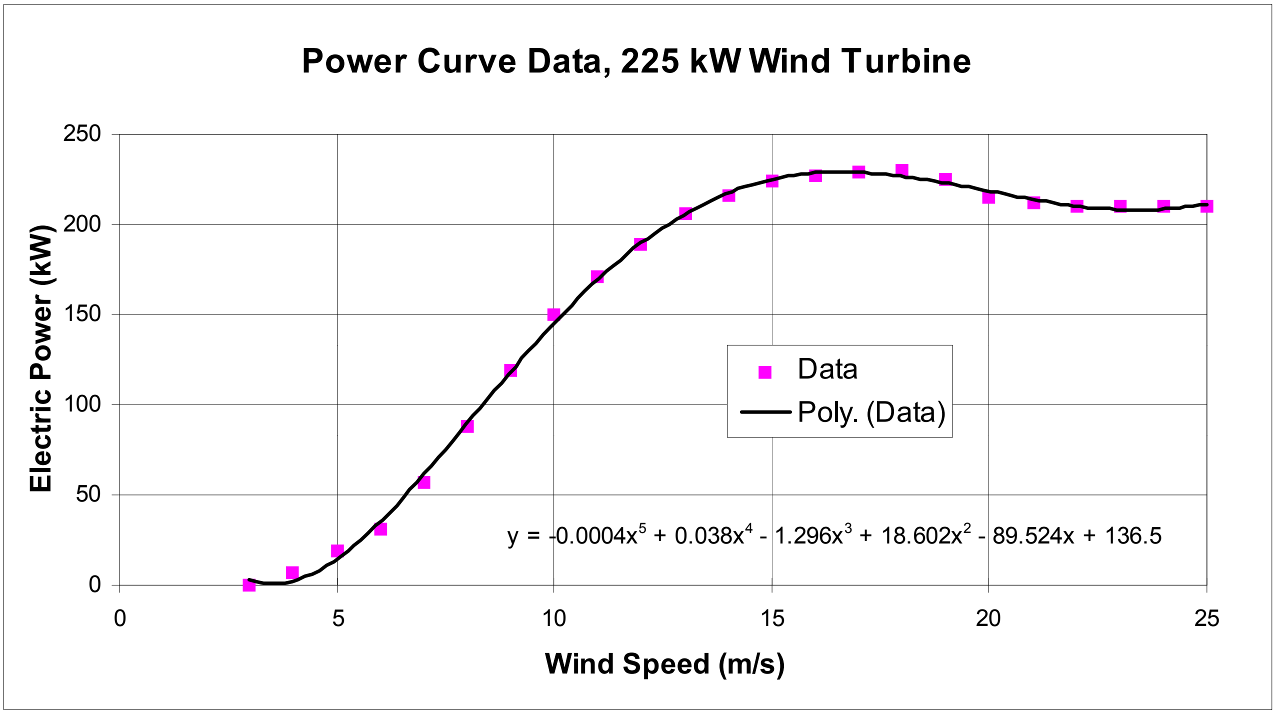

Figure 30: Power Curve, NM 225-30 (225 kW) Wind Turbine

4.3 Wind Energy vs Load Profile Correlation

The hybrid system model used hourly load data derived by combining hourly diesel production data with wind production based on hourly wind speed data. The evidence of the power production statistics in Section 2.3 indicates the loads at SCI grew 10% per year from 1996 through 1998. Several new buildings and facilities would indicate a more substantial load increase in 1999. The load frequency distribution was shown earlier in Figure 3.

Short-term load variability is defined as 0.135 based on the following rationale: the average load, 846 kW, gives 1 sigma (one standard deviation) = 114 kW and 3 sigma = 342 kW. These values would require very large operating margins. However, the change in demand from one hour to the next is lower using the derived SCI hourly demand data, with an average of 48 kW and a peak of 287 kW. These fluctuations coincide with operating experience, which has demonstrated about 50 kW normal fluctuation and an occasional 100-kW to 300-kW demand step or spike. The hybrid spreadsheet model accommodates this fluctuation by reserving a 300-kW margin of diesel capacity above the net demand for each 12-hour period.

The hourly wind speed averages from 1998 composite data set was used in the hybrid-system model. Both wind and load data were arranged to a calendar year to assure proper synchronization. The wind frequency distribution was presented earlier in Figure 14. Annual diurnal wind speed and load are overlaid in Figure 31. Both the diurnal load and wind speed are relatively steady, with the diurnal wind speed cycling between 5.4 and 7.7 m/s, giving a somewhat neutral correlation.

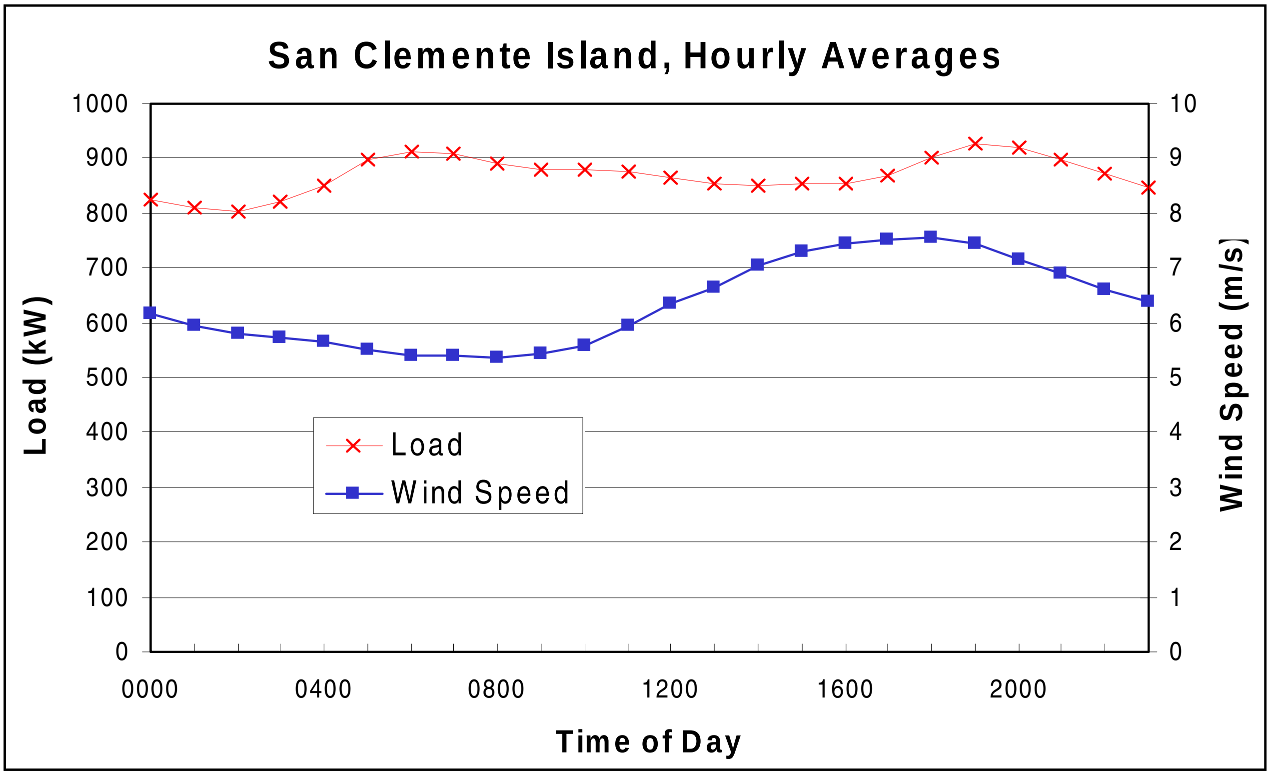

Figure 31: SCI Diurnal Load and Wind Speed Overlay

4.4 Energy System Operating Results

Using the first year's operating data with two 225 kW wind turbines (February 1998 through January 1999), the diesel energy production and fuel consumption fell by 11.2%. More detail is given in the monthly power plant production logs in Appendix B. The wind turbines were not fully utilized during this time because of initial startup and adjustment activities and subsequent grid problems and construction activities.

4.5 Hybrid System Spreadsheet Model

The hybrid system model uses the existing wind-diesel system plus new wind generation; the load data are from SCI 1998 operating data and the wind data are from the NREL/SCI 1996 through 1999 measurements. The spreadsheet model starts by calculating a diesel rating that covers the load demand with sufficient margin to ensure a minimum diesel run time of 12 hours and capable of handling 400-kW excursions. Diesel consumption for a diesel-only baseline system is calculated next, based on demand and efficiency. Finally, the number of diesel starts and run time are computed.

The wind-diesel hybrid section follows by calculating the power produced by a single wind turbine for each hour of the year. Then it calculates the optimal wind power usage by choosing the greatest number of turbines to operate without exceeding demand, and while maintaining at least 200 kW of diesel energy online. This wind power, when subtracted from the demand, reduces the amount of power required from the diesel generators. Only in very low or very high winds are the diesel power demand unchanged. Diesel fuel consumption is then calculated from this net demand and fed into the fuel savings over the baseline system.

Four different cases of the wind-diesel hybrid system were examined. The results are summarized in Table 5. In the first case, just one 225-kW wind turbine was added to the baseline diesel system, the second case two 225-kW turbines, and so on, up to four 225-kW wind turbines. The minimum and maximum net loads (demand minus wind power) are 0 kW (loss of grid) and 1472 kW for all cases. The number of diesel starts is determined by incrementing a counter every time the diesel demand changes. The diesel run time is 8760 hours (1 diesel all year), plus the number of hours at 1700 kW capacity (2 diesels on). The diesel-only case required 100 starts and 15,491 engine-hours of total run time for the year.

Four 225 kW wind turbines reduce diesel energy production by 23.1% and fuel consumption by 17.0%. Fuel savings fall below energy savings because the high wind variability necessitates greater diesel capacity running at somewhat less efficient conditions. However, these fuel savings could be improved significantly if the diesel usage was optimized, but at the cost of starting and stopping the engines much more frequently.

Table 5: 1998 Hybrid Systems vs Baseline:
Spreadsheet Model Results

Hybrid Results Parameter	Units	Baseline Diesel Only	1 Wind Turbine 225 kW	2 Wind Turbines 225 kW	3 Wind Turbines 225 kW	4 Wind Turbines 225 kW
Average WS, 1yr	m/s	6.1	6.1	6.1	6.1	6.1
Average Load, 1yr	kW	870	870	870	870	870
Run Duration	hour	8,760	8,760	8,760	8,760	8,760
Avg Net Diesel Load (1), kW		870	817	763	711	669
Energy Demand, 1yr	MWh	7618	7618	7618	7618	7618
Diesel Energy, 1yr	MWh	7618	7153	6687	6232	5856
Wind Energy, Used	MWh	0	466	931	1386	1762
Wind Energy, Unused	MWh	0	0	0	10	100
Diesel Energy	%	100.0	93.9	87.8	81.8	76.9
Wind Energy	%	0.0	6.1	12.2	18.2	23.1
Wind Energy Incremental Turbine %		0.0	6.1	6.1	6.0	4.9
Wind System Capacity Factor % (2)		n/a	23.6	23.6	23.4	22.3
Wind Sys Inctl Turbine Cap Fac %		n/a	23.6	23.6	23.1	19.1
Fuel Usage	kltr	2689	2568	2447	2329	2232
Fuel Usage	% of base	0.0	95.5	91.0	86.6	83.0
Fuel Saving	kltr	0	121	242	360	457
Wind Energy COE	$/kWh	n/a	0.152	0.142	0.138	0.139
Effective Wind COE (3), $/kWh		n/a	0.361	0. 353	0.350	0.351
Hybrid System COE	$/kWh	0.476	0.469	0.461	0.453	0.447
System COE Saving	$/kWh	0.000	0.007	0.015	0.023	0.029
System COE Saving	% of base	0.0	1.5	3.2	4.8	6.1
Payback Period	year	n/a	7.00	6.49	6.28	6.32
Internal Rate of Return, %		n/a	13.1	14.4	14.9	14.8

Notes:

(1) "Net Diesel Load" means net power required from the diesels, or system load minus useable wind power.
(2) Wind System Capacity Factor = Wind Energy [MWh] / (#turbines*rating[0.225MW]*8760[h]).
(3) Effective Wind Cost of Energy (COE) = (hybrid COE*energy demand - baseline COE*diesel energy) / wind energy.
(4) All other values derived from spreadsheet model results, Appendix A.
(5) For efficiency, this table includes some of the economic results developed and discussed in the next section.

5.0 COST ANALYSIS

5.1 Methodology

After estimating 1998 operating costs for the four cases of the wind-diesel hybrid system and for the baseline diesel-only system, the resulting levelized costs of energy (COE) were compared. Also, payback periods were computed for the four cases of hybrid system investment. COE is derived using

$$COE = NPV * CRFI / AEP,$$

where NPV is the total net present value of all system costs, CRFI is the capital recovery factor for system income, and AEP is annual energy production (system load). A simple payback period is calculated by dividing the total initial capital cost by the annual savings from system operation, which includes the difference in fuel, overhaul, and operations and maintenance (O&M) costs between the wind-diesel hybrid and baseline systems [4].

Economic assumptions included 2% general inflation, 2% fuel inflation, 6.9% discount rate, 20 year system life, and 100% down payment on new investment. Although new wind turbines will start with a 20-year life, the existing diesel systems have been in service for several years and have limited lives of their own. This is covered by a fund for major diesel overhauls. It was further assumed that no additional labor would be required to operate the wind-diesel hybrid plant beyond that already assigned to operate the existing diesel power plant.

5.2 Diesel System Costs

The diesel system operating costs are derived partly from San Nicolas Island cost data because the San Clemente Island information is incomplete. Fuel costs are based on various memos, email and verbal conversations with the PWC.

Since a full breakdown of SCI power system costs was not available, we resorted to the rate SCI charges its customers: $0.390 / kWh, which gives $2,971,205 for 7,618,475 kWh. The inherent assumption is that this rate reflects true and total life-cycle costs for the SCI power system without profit, since its customers are other Navy entities and their subcontractors. We suspect the true diesel system costs are lower, but don’t have any other basis to work with at this time.

The fuel price also is known, at $0.206/liter ($0.78/gal), and adding transportation and other hidden costs bring the total fuel cost up to $0.264/liter ($1.00/gal). That translates into $0.082 / kWh for fuel using the baseline fuel and energy totals for 1998. The remaining amount of $0.308 / kWh is included in the O&M item in the economic analysis spreadsheet, but it must cover O&M, diesel overhauls, and eventual replacement. However, some of these costs are fixed and part variable. We will assume they split half-and-half, based on experience with similar facilities [5]. Therefore the variable part is $0.154 / kWh, and the fixed part is 0.5 * (0.308*7,618,475) = $1,173,245.

5.3 Wind Energy System Costs

Wind-diesel hybrid system costs include the baseline costs as given above, plus new costs associated with the wind turbines and interconnect and control equipment. The interconnect and control equipment are included with the wind turbine balance of station (BOS) costs, along with foundations, installation, spare parts inventory, site surveying and preparation, O&M facilities and equipment, permits and licenses, project management and engineering, and construction insurance and contingency. Initial capital costs including BOS are detailed in Table 6. If multiple turbines were installed at one time, per-unit turbine price and BOS costs would drop considerably, but we have not applied this adjustment. Also, it may be possible to further reduce installation and operation costs by utilizing Navy heavy equipment (such as a crane).

Each 225kW wind turbine costs $220,000, plus $25,000 shipping from Denmark to Los Angeles then to SCI. An additional $450,510 is required to cover BOS costs. Thus, the total capital cost required for four wind turbines is $2,742,040, when installed one at a time. If all four turbines were installed together, the overall cost would be about $2,500,000. Overhaul costs are fixed at an annual $1000 per wind turbine, regardless of turbine usage. Actual wind turbine O&M costs of $0.005/kWh are doubled to $0.01/kWh to account for the small system size and the extra burden SCI represents with its remote setting. As implied by its units, this O&M cost is variable, or fully dependent on wind turbine usage. These amounts are based on a working system using the 225 kW wind turbine.

Table 6: Initial Capital Costs for One Additional 225 kW Wind Turbine

Item	Mainland Cost	Extra Cost for SCI Access	Total SCI Cost 1998
225kW Wind Turbine	$220,000	$25,000	$245,000
Turbine installation on SCI	75,000	67,180	142,180
225kW Service Parts	3,000	400	3,400
Turbine Maintenance / Warranty	2,000	2,730	4,730
Turbine Siting	3,100	2,000	5,100
Turbine Foundation	90,000	41,000	131,000
Project Engineering	25,000	5,500	30,500
Trenching & Land Improvements	5,000	8000	13,000
Electrical Infrastructure	80,000	23,000	103,000
Electrical Maintenance / Warranty	4,000	3,600	7,600
Total	507,100	178,410	$685,510

If multiple turbines were installed together, a discount should be available on the wind turbines, and significant economies of scale would be possible with the BOS costs. Based on bids for multiple turbine projects at SCI, the initial capital cost for one wind turbine should drop by $50,000 each for two turbines, $75,000 each for three, and $100,000 each for four. These reductions are used in the economic model. However, the wind farm at SCI began with two units and will have a third and a fourth added at different times.

5.4 Wind-Diesel Hybrid System Operational Savings

Once all of the engineering and cost data were ready, an economic assessment was performed according to the procedure used in Hunter [4]. Figure 32 shows the resulting COE decreasing as the number of wind turbines increases. The trend will eventually reverse and start to increase with number of turbines, each additional wind turbine would be less efficiently utilized because of the growing wind energy penetration and lack of system storage. For this same reason, Figures 33 and 34 show the payback period dropping and the internal rate of return rising from one to three turbines and then leveling and reversing thereafter. The complete economic tables can be found in Appendix A. These results are provided for those who need data points to check their own simulations. Copies of the spreadsheets used here can be obtained from the authors.

The $1,271,000 capital investment in the two-turbine hybrid system was easily offset by savings in fuel and operating costs for diesel generation of $196,000 annually, giving a 6.49 year simple payback period, 14.4% internal rate of return, $0.142/kWh wind COE, and dropping the system COE from $0.476/kWh to $0.461/kWh. This would give net savings of $0.015/kWh, or $114,000 in 1998. Using the EPRI TAG approach gives a wind energy COE = (ICC*FCR)/AEP + O&M = (635510*.102) / 466000 + 0.01 = $0.149/kWh.

With a capital investment of $2,342,000, four 225 kW wind turbines have annual operating savings of $370,000, and would give a 6.32 year simple payback period, 14.8% internal rate of return, $0.139/kWh wind COE, and $0.447/kWh system COE, with net savings of $0.029/kWh, or $223,000 in 1998.

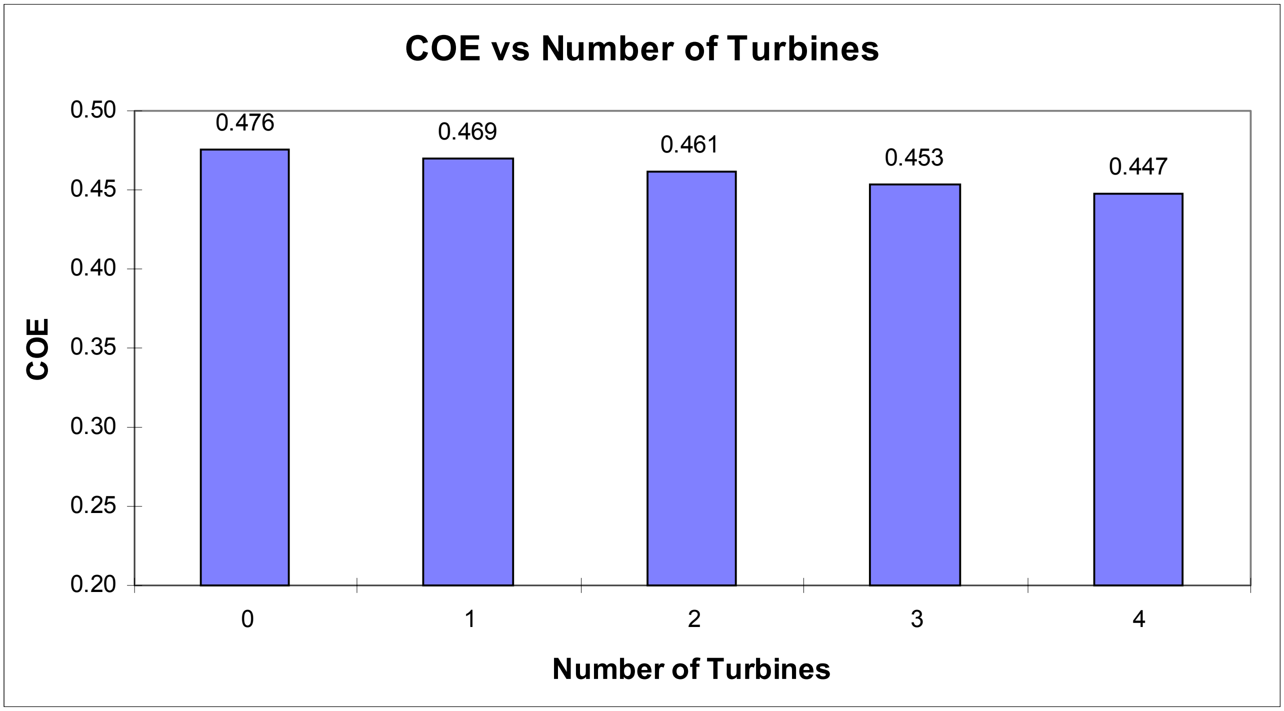

Figure 32: System COE vs Number of Wind Turbines

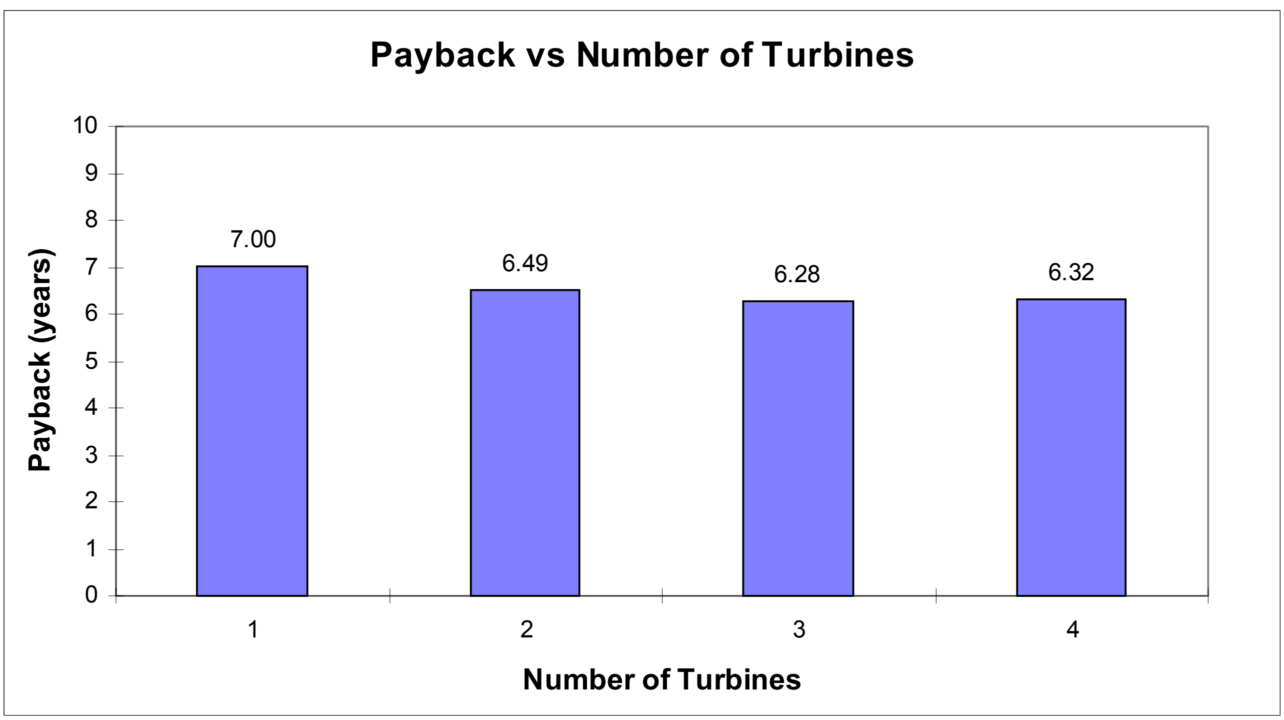

Figure 33: Payback Period vs Number of Wind Turbines

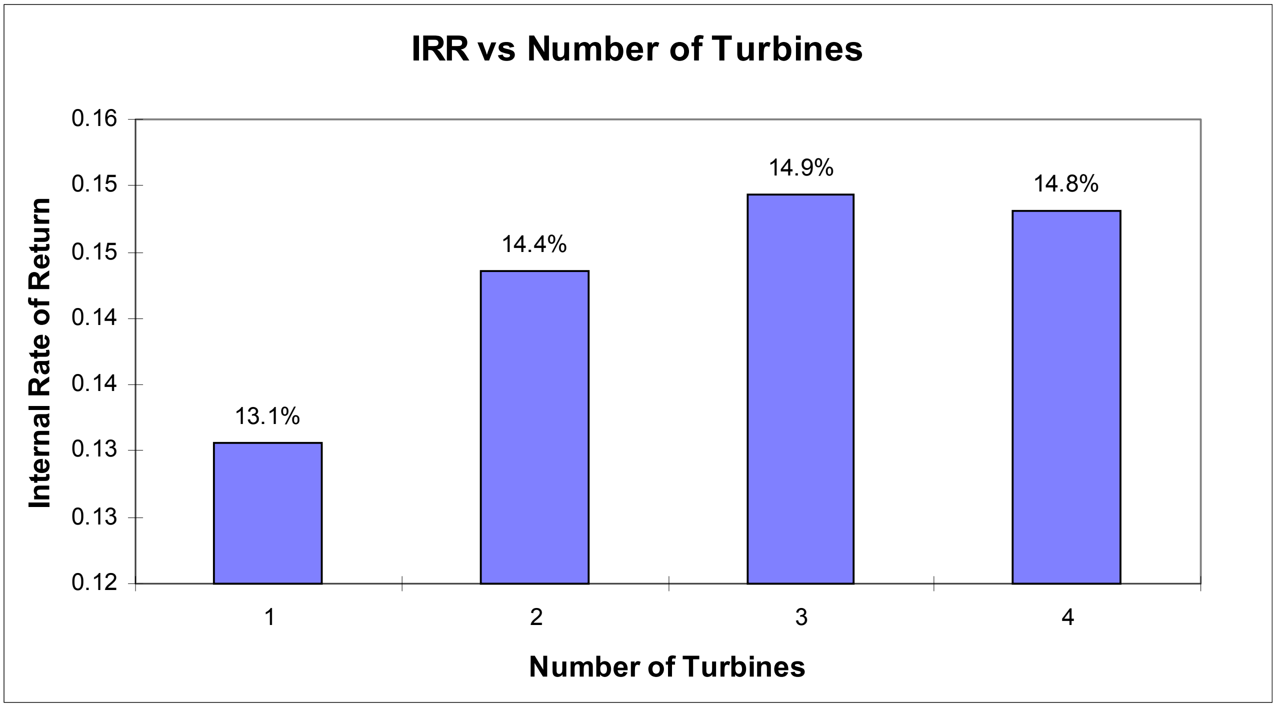

Figure 34: Internal Rate of Return vs Number of Wind Turbines

5.5 Sensitivity Analysis

To check the sensitivity of the results to variations in average wind speed from year to year, the two-turbine case was run with the wind speeds adjusted upward and downward by 17.5%, which is the interannual variability (one standard deviation) found in the historical wind measurements. The results are shown in Table 7. With the wind speed 17.5% lower than the NREL measurement year, COE and payback period rose by 2.6% and 63%. With the wind speed 17.5% higher, COE and payback period dropped by 2.6% and 28%.

Table 7: Economic Sensitivity to Wind Speed Variations
Spreadsheet Model for 2 Turbines

Case	Wind Speed	Diesel Saving (kltr)	Cost of Energy ($/kWh)	Payback Period (years)	Internal Rate of Return (%)
minus 17.5%	5.0 m/s	149	0.473	10.6	7.0
baseline	6.1 m/s	242	0.461	6.5	14.4
plus 17.5%	7.2 m/s	336	0.449	4.7	21.0

The wind energy COE of $0.15/kWh is much higher than the typical range of $0.04/kWh to $0.09/kWh. Several factors contribute to this discrepancy, including costs associated with island access, severe Naval construction requirements, and moderately low wind speeds at this site. To gain some understanding of the COE sensitivity to these issues, we ran an economic case for two turbines without the severe Naval and island access requirements. This case uses mainland costs with those for installation, foundation, and electrical infrastructure reduced by half, plus a $30,000 discount for each of two turbines. The net initial capital cost of $354,600 per turbine generates a wind energy COE of $0.086/kWh, a hybrid system COE of $0.454/kWh, a payback period of 3.6 years, and a 27.4% internal rate of return. Using the EPRI TAG approach gives COE = (ICC*FCR)/AEP + O&M = (354600*.102) / 466000 + 0.01 = $0.088/kWh.

6.0 CONCLUSIONS

San Clemente Island (SCI) has a moderate wind resource, with an annual average wind speed of 6.1 m/s (11.6 knots) as measured by the National Renewable Energy Laboratory and the Naval Facilities Engineering Service Center at the Met2 tower wind site location from the 1995 through 1999 data collection period. Recognizing this, the recently constructed wind-diesel hybrid energy system was modeled to examine its performance and economics, as well as the merits of adding more wind energy generation. Using generally conservative assumptions (unfavorable to wind energy) in the model, the hybrid system displayed favorable operation and economics.

Using two 225 kW wind turbines, the wind energy COE of $0.142/kWh helps reduce the wind-diesel hybrid system COE from the baseline $0.476/kWh to $0.461/kWh. This reduces system COE by 3.2%. The payback period is 6.5 years, the internal rate of return 14.4%. The four-turbine case had a wind energy COE of $0.139/kWh and a hybrid system COE of $0.447/kWh, saving 6.1%. The payback period is 6.3 years, the internal rate of return 14.8%.

The costs of energy (COE) for this case is relatively insensitive to annual average wind speed, varying 2.6% for a 17.5% change in wind speed. But the payback period is quite sensitive to wind speed, varying 28% to 63% for a 17.5% change in wind speed. Different economic assumptions, such as higher and lower inflation, do not appear to have much impact on the results. Because cost and savings components are well distributed, there does not appear to be a dominant factor affecting the economic results. Factors that could affect the results include the actual capital and installation costs of the wind equipment, diesel fuel costs, and diesel system O&M and overhaul costs.

This work presented a study of the SCI wind-diesel hybrid system using two wind turbines with an option for two more. For the operating and economic conditions examined, it appears wind energy is cost effective in this application. We believe these conditions are realistic but regret the lack of complete cost data on the existing diesel system. Certainly many alternatives to these cases merit consideration. For instance, it appears that the wind penetration could be increased, thus producing further, yet diminishing, savings.

Moreover, excess electrical energy should not be curtailed or wasted on dump loads; rather, it should be used for beneficial purposes, provided those purposes make economic sense. Within the SCI electrical grid, such benefits may be realized by using excess wind energy for deferrable loads such as the SCI reverse osmosis water system, water heating, or space heating. The Navy is planning for a reverse osmosis water system with its fourth wind turbine in 2001.

As a preliminary review, this study used 1-hour average wind and load data for the hybrid system modeling to develop a general sense of economic tradeoffs. Dynamic load management should be addressed using load and wind data at shorter intervals (1 minute or less) to study system dynamics.

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APPENDIX A:
Hybrid System Model and Economic Summary Tables

This appendix contains the hybrid system model and economic summary tables used to develop the economic conclusions reached in this report.

SAN CLEMENTE ISLAND HYBRID SYSTEM MODEL

Maximum number of wind turbines: 1

		diesel only----->						wind hybrid----->											98.4 ft
Date	Time (hr)	Demand (kW)	Diesel Rating (kW)	Percent of Rating Used	Litres of Diesel Consumed	starts counter	Diesel run time (hours)	Adjusted Wind Speed (m/s)	Single Turbine Wind Power (kW)	Maximum Allowed Wind Demand (kW)	Number of Turbines	Net Demand (kW)	Diesel Rating (kW)	Percent of Rating Used	Litres of Diesel Consumed	starts counter	Diesel run time (hours)	litres saved	Original Wind Speed 6.1 m/s
Average		869.7	1531.7	58%	306.9			6.1	53.1	669.7	0.8	816.5	1448.9	0.5	293.2			13.7844	6.119481
Standard Deviation		114.0	236.3	8%	37.9			3.1	60.9	114.0	0.4	107.0	250.0	0.1	35.5			15.80659	3.10947
Maximum		1519.1	1700.0	89%	484.3			21.6	229.4	1319.1	1.0	1289.8	1700.0	0.8	424.9			59.48818	21.62711
Minimum		514.2	1200.0	32%	197.1			0.3	0.0	314.2	0.0	489.8	1200.0	0.3	197.1			0	0.300872
Total		7618476			2688873	196	14572		465547	5866476		7152929			2568122	220	13121	120751	

465547 Wind Energy Used
465547 Wind Energy Available
0 Wind Energy Curtailed

Maximum number of wind turbines: 2

		diesel only----->						wind hybrid----->											98.4 ft
Date	Time (hr)	Demand (kW)	Diesel Rating (kW)	Percent of Rating Used	Litres of Diesel Consumed	starts counter	Diesel run time (hours)	Adjusted Wind Speed (m/s)	Single Turbine Wind Power (kW)	Maximum Allowed Wind Demand (kW)	Number of Turbines	Net Demand (kW)	Diesel Rating (kW)	Percent of Rating Used	Litres of Diesel Consumed	starts counter	Diesel run time (hours)	litres saved	Original Wind Speed 6.1 m/s
Average		869.7	1531.7	58%	306.9			6.1	53.1	669.7	1.7	763.4	1393.1	0.5	279.4			27.5688	6.119481
Standard Deviation		114.0	236.3	8%	37.9			3.1	60.9	114.0	0.7	131.6	243.6	0.1	39.8			31.61318	3.10947
Maximum		1519.1	1700.0	89%	484.3			21.6	229.4	1319.1	2.0	1277.8	1700.0	0.8	421.7			119	21.62711
Minimum		514.2	1200.0	32%	197.1			0.3	0.0	314.2	0.0	261.1	750.0	0.2	154.8			0	0.300872
Total		7618476			2688873	196	14572		465547	5866476		6687381			2447371	236	12144	241503	

931095 Wind Energy Used
931095 Wind Energy Available
0 Wind Energy Curtailed

Maximum number of wind turbines: 3

		diesel only----->						wind hybrid----->											98.4 ft
Date	Time (hr)	Demand (kW)	Diesel Rating (kW)	Percent of Rating Used	Litres of Diesel Consumed	starts counter	Diesel run time (hours)	Adjusted Wind Speed (m/s)	Single Turbine Wind Power (kW)	Maximum Allowed Wind Demand (kW)	Number of Turbines	Net Demand (kW)	Diesel Rating (kW)	Percent of Rating Used	Litres of Diesel Consumed	starts counter	Diesel run time (hours)	litres saved	Original Wind Speed 6.1 m/s
Average		869.7	1531.7	58%	306.9			6.1	53.1	669.7	2.5	711.4	1355.1	0.5	265.9			41	6.119481
Standard Deviation		114.0	236.3	8%	37.9			3.1	60.9	114.0	1.1	172.0	247.3	0.1	48.3			46.75209	3.10947
Maximum		1519.1	1700.0	89%	484.3			21.6	229.4	1319.1	3.0	1277.8	1700.0	0.8	421.7			178.4645	21.62711
Minimum		514.2	1200.0	32%	197.1			0.3	0.0	314.2	0.0	201.0	750.0	0.1	116.1			0	0.300872
Total		7618476			2688873	196	14572		465547	5866476		6232205			2329309	282	11618	359564	

1386271 Wind Energy Used
1396642 Wind Energy Available
10371 Wind Energy Curtailed

Maximum number of wind turbines: 4

		diesel only----->						wind hybrid----->											98.4 ft
Date	Time (hr)	Demand (kW)	Diesel Rating (kW)	Percent of Rating Used	Litres of Diesel Consumed	starts counter	Diesel run time (hours)	Adjusted Wind Speed (m/s)	Single Turbine Wind Power (kW)	Maximum Allowed Wind Demand (kW)	Number of Turbines	Net Demand (kW)	Diesel Rating (kW)	Percent of Rating Used	Litres of Diesel Consumed	starts counter	Diesel run time (hours)	litres saved	Original Wind Speed 6.1 m/s
Average		869.7	1531.7	58%	306.9			6.1	53.1	669.7	3.3	668.5	1328.3	0.4	254.8			52	6.119481
Standard Deviation		114.0	236.3	8%	37.9			3.1	60.9	114.0	1.4	201.7	259.2	0.1	55.0			57.26681	3.10947
Maximum		1519.1	1700.0	89%	484.3			21.6	229.4	1319.1	4.0	1277.8	1700.0	0.8	421.7			237.9527	21.62711
Minimum		514.2	1200.0	32%	197.1			0.3	0.0	314.2	0.0	200.2	750.0	0.1	116.1			0	0.300872
Total		7618476			2688873	196	14572		465547	5866476		5856374			2231828	312	11367	457045	

1762102 Wind Energy Used
1862189 Wind Energy Available
100087 Wind Energy Curtailed

ECONOMIC ANALYSIS | **Site:** San Clemente Island, CA, 6.1 m/s avg
Turbine: 225 kW, Commercial
Quantity: 1

Input Values

System load (kWh/y)	SL	7,618,476
Diesel energy (kWh/y)		7,152,929
Wind energy (kWh/y)		465,547
Diesel fuel usage, no wind (l/yr)	FL	2,688,873
Diesel fuel usage, with wind (l/yr)	FL	2,568,122
Diesel fuel cost ($/l)	FC	0.264
Diesel ops cost, variable ($/kWh)	OV	0.154
Diesel ops cost, fixed ($/y)	OF	1,173,245
Wind ICC ($)	WC	685,510
Wind O&M cost ($/kWh)	WO	0.01
System life, (yrs)	L	20
General inflation	i	2.0%
Fuel inflation	e	2.0%
Discount rate	d	6.9%
Interest	b	10.0%
Term of loan, (yrs)	N	10

Economic Factors

	a variable	n variable	Y(a,n)
Present worth factor of fuel costs, PWFF, a=(1+e)/(1+d)	0.95416277	20	12.67203
Present worth factor of O&M costs, PWFO, a=(1+i)/(1+d)	0.95416277	20	12.67203
Present worth factor of interest payments, PWFP, a=1/(1+b)	0.9354537	10	7.05616

	a variable	n variable	X(a,n)
Capital recovery factor for system income, CRFI, a=1/(1+d)	0.9354537	20	0.09366054
Capital recovery factor for interest payments, CRFP, a=1/(1+b)	0.90909091	10	0.16274539

Calculated Values for Both Systems

		Diesel Only	Hybrid System Diesel Part	Hybrid System Wind Part	Hybrid System Total
Capital cost	C = ICC+BOS	0	0	685,510	685,510
Initial payment on system	Ad	0	0	685,510	685,510
Loan	Al = C - Ad	0	0	0	0
Annual payment	Ap = Al * CRFP	0	0	0	0
NPV of annual payment	Apnpv = Ap*PWFP	0	0	0	0
Fuel cost per annum	Af = FL * FC	709,863	677,984	0	677,984
NPV of fuel costs	Afnpv = Af * PWFF	8,995,402	8,591,439	0	8,591,439
Overhaul cost per annum	Ao	0	0	1,000	1,000
NPV of overhaul costs	Aonpv = Ao * PWFO	0	0	12,672	12,672
O&M costs per annum	Am	2,346,490	2,274,796	4,655	2,279,451
NPV of O&M costs	Amnpv = Am*PWFO	29,734,802	28,826,290	58,994	28,885,284
Total annual costs	At = Ap+Af+Ao+Am	3,056,353	2,952,780	5,655	2,958,436
Total system NPV, TNPV	= Ad+sum(NPVs)	38,730,204	37,417,728	757,176	38,174,905
Annual savings	Sv = dsl At - hbd At				97,917
Levelized cost of energy, COE	= TNPV*CRFI/SL	0.476	0.490	0.152	0.469
Payback period, years					7.00
Internal rate of return, IRR, (x)	[(1+x)^L-1]/[x*(1+x)^L] - P =		0.000		13.1%

(NPV = net present value; ICC = initial capitol cost; BOS = balance of station = 26% ICC; O&M = operations and maintenance)

ECONOMIC ANALYSIS

Site: **San Clemente Island, CA, 5.0 m/s avg**
Turbine: **225 kW, Commercial**
Quantity: **2**

Input Values

System load (kWh/y)	SL	7,618,476
Diesel energy (kWh/y)		7,042,272
Wind energy (kWh/y)		576,204
Diesel fuel usage, no wind (l/yr)	FL	2,688,873
Diesel fuel usage, with wind (l/yr)	FL	2,539,421
Diesel fuel cost ($/l)	FC	0.264
Diesel ops cost, variable ($/kWh)	OV	0.154
Diesel ops cost, fixed ($/y)	OF	1,173,245
Wind ICC ($)	WC	635,510
Wind O&M cost ($/kWh)	WO	0.01
System life, (yrs)	L	20
General inflation	i	2.0%
Fuel inflation	e	2.0%
Discount rate	d	6.9%
Interest	b	10.0%
Term of loan, (yrs)	N	10

Economic Factors

	a variable	n variable	Y(a,n)
Present worth factor of fuel costs, PWFF, a=(1+e)/(1+d)	0.95416277	20	12.67203
Present worth factor of O&M costs, PWFO, a=(1+i)/(1+d)	0.95416277	20	12.67203
Present worth factor of interest payments, PWFP, a=1/(1+b)	0.9354537	10	7.05616

	a variable	n variable	X(a,n)
Capital recovery factor for system income, CRFI, a=1/(1+d)	0.9354537	20	0.09366054
Capital recovery factor for interest payments, CRFP, a=1/(1+b)	0.90909091	10	0.16274539

Calculated Values for Both Systems

		Diesel Only	Hybrid System Diesel Part	Hybrid System Wind Part	Hybrid System Total
Capital cost	C = ICC+BOS	0	0	1,271,020	1,271,020
Initial payment on system	Ad	0	0	1,271,020	1,271,020
Loan	Al = C - Ad	0	0	0	0
Annual payment	Ap = Al * CRFP	0	0	0	0
NPV of annual payment	Apnpv = Ap*PWFP	0	0	0	0
Fuel cost per annum	Af = FL * FC	709,863	670,407	0	670,407
NPV of fuel costs	Afnpv = Af * PWFF	8,995,402	8,495,420	0	8,495,420
Overhaul cost per annum	Ao	0	0	2,000	2,000
NPV of overhaul costs	Aonpv = Ao * PWFO	0	0	25,344	25,344
O&M costs per annum	Am	2,346,490	2,257,755	5,762	2,263,517
NPV of O&M costs	Amnpv = Am*PWFO	29,734,802	28,610,344	73,017	28,683,361
Total annual costs	At = Ap+Af+Ao+Am	3,056,353	2,928,162	7,762	2,935,924
Total system NPV, TNPV	= Ad+sum(NPVs)	38,730,204	37,105,764	1,369,381	38,475,145
Annual savings	Sv = dsl At - hbd At				120,429
Levelized cost of energy, COE	= TNPV*CRFI/SL	0.476	0.493	0.223	0.473
Payback period, years					10.55
Internal rate of return, IRR, (x)	[(1+x)^L-1]/[x*(1+x)^L] - P =		0.000		7.0%

(NPV = net present value; ICC = initial capitol cost; BOS = balance of station = 26% ICC; O&M = operations and maintenance)

ECONOMIC ANALYSIS

Site: San Clemente Island, CA, 6.1 m/s avg
Turbine: 225 kW, Commercial
Quantity: 2

Input Values

System load (kWh/y)	SL	7,618,476
Diesel energy (kWh/y)		6,687,381
Wind energy (kWh/y)		931,095
Diesel fuel usage, no wind (l/yr)	FL	2,688,873
Diesel fuel usage, with wind (l/yr)	FL	2,447,371
Diesel fuel cost ($/l)	FC	0.264
Diesel ops cost, variable ($/kWh)	OV	0.154
Diesel ops cost, fixed ($/y)	OF	1,173,245
Wind ICC ($)	WC	635,510
Wind O&M cost ($/kWh)	WO	0.01
System life, (yrs)	L	20
General inflation	i	2.0%
Fuel inflation	e	2.0%
Discount rate	d	6.9%
Interest	b	10.0%
Term of loan, (yrs)	N	10

Economic Factors

	a variable	n variable	Y(a,n)
Present worth factor of fuel costs, PWFF, a=(1+e)/(1+d)	0.95416277	20	12.67203
Present worth factor of O&M costs, PWFO, a=(1+i)/(1+d)	0.95416277	20	12.67203
Present worth factor of interest payments, PWFP, a=1/(1+b)	0.9354537	10	7.05616

	a variable	n variable	X(a,n)
Capital recovery factor for system income, CRFI, a=1/(1+d)	0.9354537	20	0.09366054
Capital recovery factor for interest payments, CRFP, a=1/(1+b)	0.90909091	10	0.16274539

Calculated Values for Both Systems

		Diesel Only	Hybrid System Diesel Part	Hybrid System Wind Part	Hybrid System Total
Capital cost	C = ICC+BOS	0	0	1,271,020	1,271,020
Initial payment on system	Ad	0	0	1,271,020	1,271,020
Loan	Al = C - Ad	0	0	0	0
Annual payment	Ap = Al * CRFP	0	0	0	0
NPV of annual payment	Apnpv = Ap*PWFP	0	0	0	0
Fuel cost per annum	Af = FL * FC	709,863	646,106	0	646,106
NPV of fuel costs	Afnpv = Af * PWFF	8,995,402	8,187,475	0	8,187,475
Overhaul cost per annum	Ao	0	0	2,000	2,000
NPV of overhaul costs	Aonpv = Ao * PWFO	0	0	25,344	25,344
O&M costs per annum	Am	2,346,490	2,203,102	9,311	2,212,413
NPV of O&M costs	Amnpv = Am*PWFO	29,734,802	27,917,777	117,989	28,035,766
Total annual costs	At = Ap+Af+Ao+Am	3,056,353	2,849,208	11,311	2,860,519
Total system NPV, TNPV	= Ad+sum(NPVs)	38,730,204	36,105,252	1,414,353	37,519,605
Annual savings	Sv = dsl At - hbd At				195,834
Levelized cost of energy, COE	= TNPV*CRFI/SL	0.476	0.506	0.142	0.461
Payback period, years					6.49
Internal rate of return, IRR, (x)	[(1+x)^L-1]/[x*(1+x)^L] - P =		0.000		14.4%

(NPV = net present value; ICC = initial capitol cost; BOS = balance of station = 26% ICC; O&M = operations and maintenance)

ECONOMIC ANALYSIS | **Site:** San Clemente Island, CA, 7.2 m/s avg
Turbine: 225 kW, Commercial
Quantity: 2

Input Values

System load (kWh/y)	SL	7,618,476
Diesel energy (kWh/y)		6,323,127
Wind energy (kWh/y)		1,295,349
Diesel fuel usage, no wind (l/yr)	FL	2,688,873
Diesel fuel usage, with wind (l/yr)	FL	2,352,892
Diesel fuel cost ($/l)	FC	0.264
Diesel ops cost, variable ($/kWh)	OV	0.154
Diesel ops cost, fixed ($/y)	OF	1,173,245
Wind ICC ($)	WC	635,510
Wind O&M cost ($/kWh)	WO	0.01
System life, (yrs)	L	20
General inflation	i	2.0%
Fuel inflation	e	2.0%
Discount rate	d	6.9%
Interest	b	10.0%
Term of loan, (yrs)	N	10

Economic Factors

	a variable	n variable	Y(a,n)
Present worth factor of fuel costs, PWFF, a=(1+e)/(1+d)	0.95416277	20	12.67203
Present worth factor of O&M costs, PWFO, a=(1+i)/(1+d)	0.95416277	20	12.67203
Present worth factor of interest payments, PWFP, a=1/(1+b)	0.9354537	10	7.05616

	a variable	n variable	X(a,n)
Capital recovery factor for system income, CRFI, a=1/(1+d)	0.9354537	20	0.09366054
Capital recovery factor for interest payments, CRFP, a=1/(1+b)	0.90909091	10	0.16274539

Calculated Values for Both Systems

		Diesel Only	Hybrid System Diesel Part	Hybrid System Wind Part	Hybrid System Total
Capital cost	C = ICC+BOS	0	0	1,271,020	1,271,020
Initial payment on system	Ad	0	0	1,271,020	1,271,020
Loan	Al = C - Ad	0	0	0	0
Annual payment	Ap = Al * CRFP	0	0	0	0
NPV of annual payment	Apnpv = Ap*PWFP	0	0	0	0
Fuel cost per annum	Af = FL * FC	709,863	621,164	0	621,164
NPV of fuel costs	Afnpv = Af * PWFF	8,995,402	7,871,405	0	7,871,405
Overhaul cost per annum	Ao	0	0	2,000	2,000
NPV of overhaul costs	Aonpv = Ao * PWFO	0	0	25,344	25,344
O&M costs per annum	Am	2,346,490	2,147,007	12,953	2,159,960
NPV of O&M costs	Amnpv = Am*PWFO	29,734,802	27,206,938	164,147	27,371,085
Total annual costs	At = Ap+Af+Ao+Am	3,056,353	2,768,170	14,953	2,783,124
Total system NPV, TNPV	= Ad+sum(NPVs)	38,730,204	35,078,343	1,460,511	36,538,854
Annual savings	Sv = dsl At - hbd At				273,229
Levelized cost of energy, COE	= TNPV*CRFI/SL	0.476	0.520	0.106	0.449
Payback period, years					4.65
Internal rate of return, IRR, (x)	[(1+x)^L-1]/[x*(1+x)^L] - P =		0.000		21.0%

(NPV = net present value; ICC = initial capitol cost; BOS = balance of station = 26% ICC; O&M = operations and maintenance)

ECONOMIC ANALYSIS | **Site:** San Clemente Island, CA, 6.1 m/s avg | **Turbine:** 225 kW, Commercial | **Quantity:** 3

Input Values		
System load (kWh/y)	SL	7,618,476
Diesel energy (kWh/y)		6,232,205
Wind energy (kWh/y)		1,386,271
Diesel fuel usage, no wind (l/yr)	FL	2,688,873
Diesel fuel usage, with wind (l/yr)	FL	2,329,309
Diesel fuel cost ($/l)	FC	0.264
Diesel ops cost, variable ($/kWh)	OV	0.154
Diesel ops cost, fixed ($/y)	OF	1,173,245
Wind ICC ($)	WC	610,510
Wind O&M cost ($/kWh)	WO	0.01
System life, (yrs)	L	20
General inflation	i	2.0%
Fuel inflation	e	2.0%
Discount rate	d	6.9%
Interest	b	10.0%
Term of loan, (yrs)	N	10

Economic Factors

	a variable	n variable	Y(a,n)
Present worth factor of fuel costs, PWFF, a=(1+e)/(1+d)	0.95416277	20	12.67203
Present worth factor of O&M costs, PWFO, a=(1+i)/(1+d)	0.95416277	20	12.67203
Present worth factor of interest payments, PWFP, a=1/(1+b)	0.9354537	10	7.05616

	a variable	n variable	X(a,n)
Capital recovery factor for system income, CRFI, a=1/(1+d)	0.9354537	20	0.09366054
Capital recovery factor for interest payments, CRFP, a=1/(1+b)	0.90909091	10	0.16274539

Calculated Values for Both Systems		Diesel Only	Hybrid System Diesel Part	Hybrid System Wind Part	Hybrid System Total
Capital cost	C = ICC+BOS	0	0	1,831,530	1,831,530
Initial payment on system	Ad	0	0	1,831,530	1,831,530
Loan	Al = C - Ad	0	0	0	0
Annual payment	Ap = Al * CRFP	0	0	0	0
NPV of annual payment	Apnpv = Ap*PWFP	0	0	0	0
Fuel cost per annum	Af = FL * FC	709,863	614,938	0	614,938
NPV of fuel costs	Afnpv = Af * PWFF	8,995,402	7,792,510	0	7,792,510
Overhaul cost per annum	Ao	0	0	3,000	3,000
NPV of overhaul costs	Aonpv = Ao * PWFO	0	0	38,016	38,016
O&M costs per annum	Am	2,346,490	2,133,005	13,863	2,146,867
NPV of O&M costs	Amnpv = Am*PWFO	29,734,802	27,029,503	175,669	27,205,172
Total annual costs	At = Ap+Af+Ao+Am	3,056,353	2,747,942	16,863	2,764,805
Total system NPV, TNPV	= Ad+sum(NPVs)	38,730,204	34,822,014	2,045,215	36,867,229
Annual savings	Sv = dsl At - hbd At				291,548
Levelized cost of energy, COE	= TNPV*CRFI/SL	0.476	0.523	0.138	0.453
Payback period, years					6.28
Internal rate of return, IRR, (x)	[(1+x)^L-1]/[x*(1+x)^L] - P =		0.000		14.9%

(NPV = net present value; ICC = initial capitol cost; BOS = balance of station = 26% ICC; O&M = operations and maintenance)

ECONOMIC ANALYSIS

Site: San Clemente Island, CA, 6.1 m/s avg
Turbine: 225 kW, Commercial
Quantity: 4

Input Values

System load (kWh/y)	SL	7,618,476
Diesel energy (kWh/y)		5,856,374
Wind energy (kWh/y)		1,762,102
Diesel fuel usage, no wind (l/yr)	FL	2,688,873
Diesel fuel usage, with wind (l/yr)	FL	2,231,828
Diesel fuel cost ($/l)	FC	0.264
Diesel ops cost, variable ($/kWh)	OV	0.154
Diesel ops cost, fixed ($/y)	OF	1,173,245
Wind ICC ($)	WC	585,510
Wind O&M cost ($/kWh)	WO	0.01
System life, (yrs)	L	20
General inflation	i	2.0%
Fuel inflation	e	2.0%
Discount rate	d	6.9%
Interest	b	10.0%
Term of loan, (yrs)	N	10

Economic Factors

	a variable	n variable	Y(a,n)
Present worth factor of fuel costs, PWFF, a=(1+e)/(1+d)	0.95416	20	12.67203
Present worth factor of O&M costs, PWFO, a=(1+i)/(1+d)	0.95416	20	12.67203
Present worth factor of interest payments, PWFP, a=1/(1+b)	0.93545	10	7.05616

	a variable	n variable	X(a,n)
Capital recovery factor for system income, CRFI, a=1/(1+d)	0.93545	20	0.09366
Capital recovery factor for interest payments, CRFP, a=1/(1+b)	0.90909	10	0.16275

Calculated Values for Both Systems

		Diesel Only	Hybrid System Diesel Part	Hybrid System Wind Part	Hybrid System Total
Capital cost	C = ICC+BOS	0	0	2,342,040	2,342,040
Initial payment on system	Ad	0	0	2,342,040	2,342,040
Loan	Al = C - Ad	0	0	0	0
Annual payment	Ap = Al * CRFP	0	0	0	0
NPV of annual payment	Apnpv = Ap*PWFP	0	0	0	0
Fuel cost per annum	Af = FL * FC	709,863	589,203	0	589,203
NPV of fuel costs	Afnpv = Af * PWFF	8,995,402	7,466,395	0	7,466,395
Overhaul cost per annum	Ao	0	0	4,000	4,000
NPV of overhaul costs	Aonpv = Ao * PWFO	0	0	50,688	50,688
O&M costs per annum	Am	2,346,490	2,075,127	17,621	2,092,748
NPV of O&M costs	Amnpv = Am*PWFO	29,734,802	26,296,072	223,294	26,519,366
Total annual costs	At = Ap+Af+Ao+Am	3,056,353	2,664,329	21,621	2,685,950
Total system NPV, TNPV	= Ad+sum(NPVs)	38,730,204	33,762,467	2,616,022	36,378,490
Annual savings	Sv = dsl At - hbd At				370,403
Levelized cost of energy, COE	= TNPV*CRFI/SL	0.476	0.540	0.139	0.447
Payback period, years	P = C / Sv				6.32
Internal rate of return, IRR, (x)	[(1+x)^L-1]/[x*(1+x)^L] - P =		0.000		14.8%

(NPV = net present value; ICC = initial capitol cost; BOS = balance of station = 26% ICC; O&M = operations and maintenance)

ECONOMIC ANALYSIS **Site:** **Fictitious Mainland Site, Non-Naval, 6.1 m/s avg**
Turbine: **225 kW, Commercial**
Quantity: **2**

Input Values

System load (kWh/y)	SL	7,618,476
Diesel energy (kWh/y)		6,687,381
Wind energy (kWh/y)		931,095
Diesel fuel usage, no wind (l/yr)	FL	2,688,873
Diesel fuel usage, with wind (l/yr)	FL	2,447,371
Diesel fuel cost ($/l)	FC	0.264
Diesel ops cost, variable ($/kWh)	OV	0.154
Diesel ops cost, fixed ($/y)	OF	1,173,245
Wind ICC ($)	WC	354,600
Wind O&M cost ($/kWh)	WO	0.01
System life, (yrs)	L	20
General inflation	i	2.0%
Fuel inflation	e	2.0%
Discount rate	d	6.9%
Interest	b	10.0%
Term of loan, (yrs)	N	10

Economic Factors

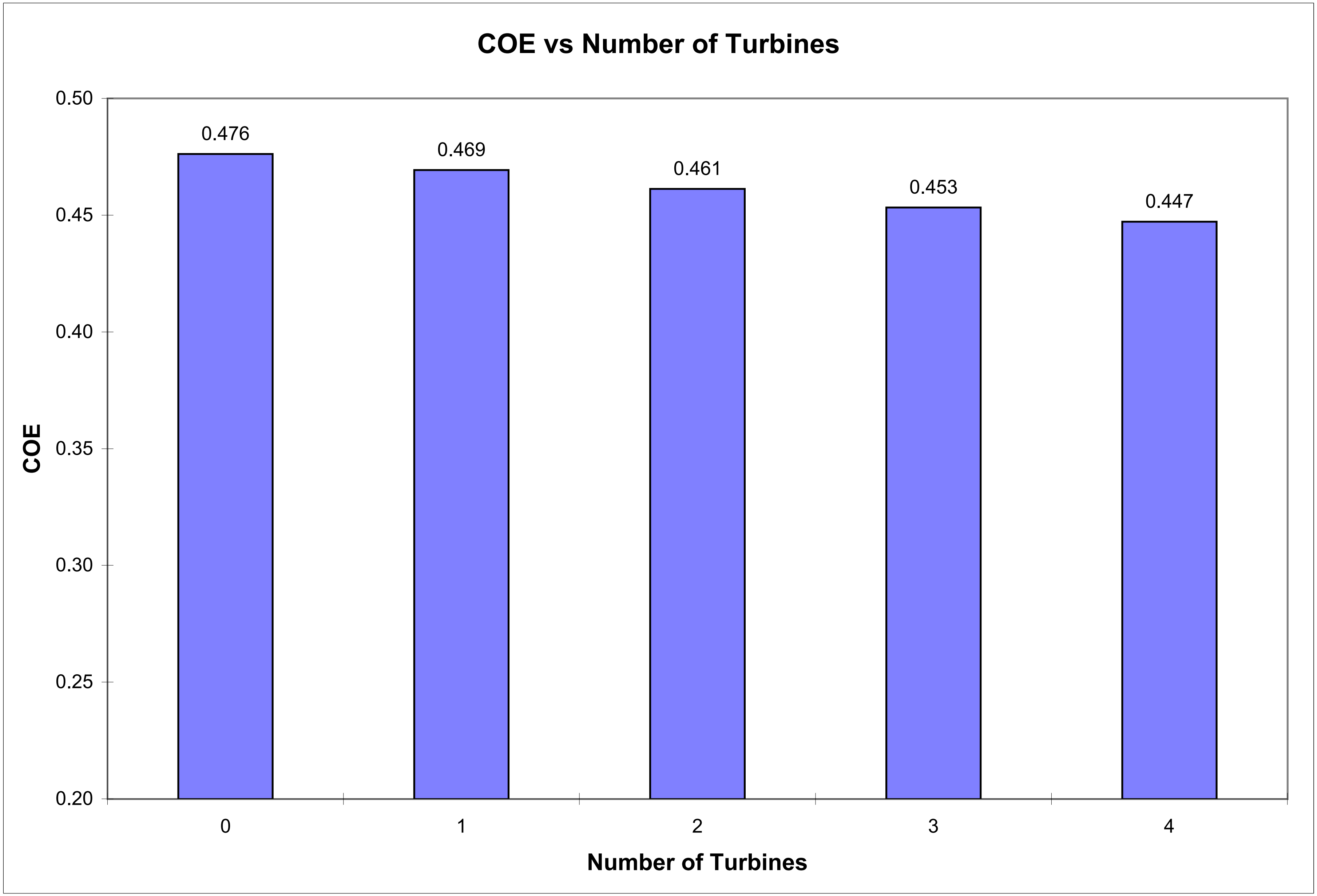
	a variable	n variable	Y(a,n)
Present worth factor of fuel costs, PWFF, a=(1+e)/(1+d)	0.95416277	20	12.67203
Present worth factor of O&M costs, PWFO, a=(1+i)/(1+d)	0.95416277	20	12.67203
Present worth factor of interest payments, PWFP, a=1/(1+b)	0.9354537	10	7.05616

	a variable	n variable	X(a,n)
Capital recovery factor for system income, CRFI, a=1/(1+d)	0.9354537	20	0.09366054
Capital recovery factor for interest payments, CRFP, a=1/(1+b)	0.90909091	10	0.16274539

Calculated Values for Both Systems

		Diesel Only	Hybrid System Diesel Part	Hybrid System Wind Part	Hybrid System Total
Capital cost	C = ICC+BOS	0	0	709,200	709,200
Initial payment on system	Ad	0	0	709,200	709,200
Loan	Al = C - Ad	0	0	0	0
Annual payment	Ap = Al * CRFP	0	0	0	0
NPV of annual payment	Apnpv = Ap*PWFP	0	0	0	0
Fuel cost per annum	Af = FL * FC	709,863	646,106	0	646,106
NPV of fuel costs	Afnpv = Af * PWFF	8,995,402	8,187,475	0	8,187,475
Overhaul cost per annum	Ao	0	0	2,000	2,000
NPV of overhaul costs	Aonpv = Ao * PWFO	0	0	25,344	25,344
O&M costs per annum	Am	2,346,490	2,203,102	9,311	2,212,413
NPV of O&M costs	Amnpv = Am*PWFO	29,734,802	27,917,777	117,989	28,035,766
Total annual costs	At = Ap+Af+Ao+Am	3,056,353	2,849,208	11,311	2,860,519
Total system NPV, TNPV	= Ad+sum(NPVs)	38,730,204	36,105,252	852,533	36,957,785
Annual savings	Sv = dsl At - hbd At				195,834
Levelized cost of energy, COE	= TNPV*CRFI/SL	0.476	0.506	0.086	0.454
Payback period, years					3.62
Internal rate of return, IRR, (x)	[(1+x)^L-1]/[x*(1+x)^L] - P =		0.000		27.4%

(NPV = net present value; ICC = initial capitol cost; BOS = balance of station = 26% ICC; O&M = operations and maintenance)


COE vs Number of Turbines
COE
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.476
0.469
0.461
0.453
0.447
0
1
2
3
4
Number of Turbines

APPENDIX B:
SCI 1998-1999 Power Plant Status and Production Reports

SCI 1998-1999 power plant status and production reports displaying the measured wind turbine and diesel electrical energy production contributing to the total San Clemente Island electrical demand. These spreadsheets indicate fuel usage, individual diesel operation and production, and individual wind turbine operation and production.

February 1998 - January 1999

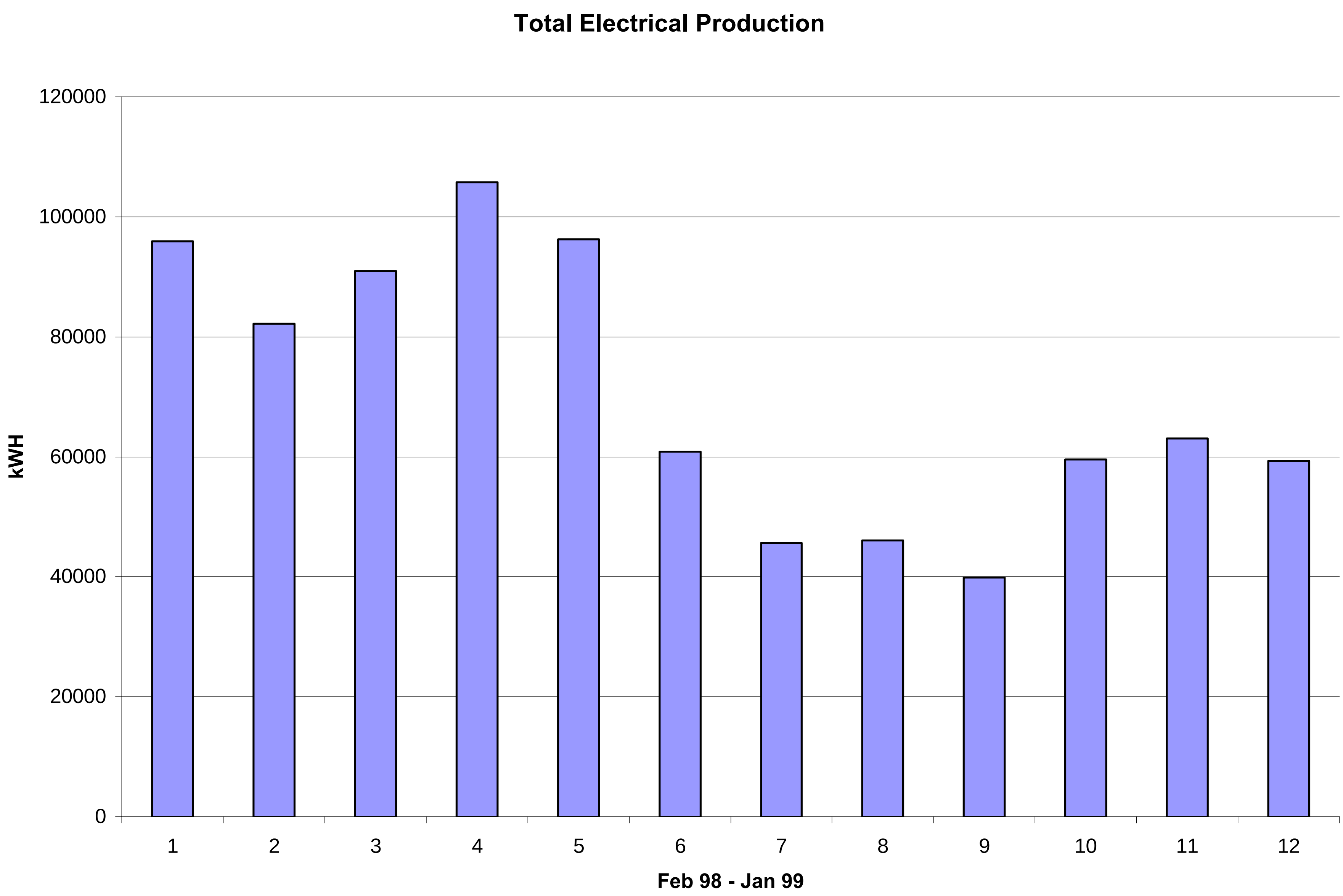
SCI Power Plant Production Report																			
	Fuel & Lube Oil Used							*Diesel Generators*				*Wind Turbines*				*Total Diesel*		*Tot. W*	*Grid Load*
	Daily		*Total*		*Daily Pk Demand*		*Avg*	*500 KW*	*500 KW*	*1.2 MW*	*750 KW*	*225 KW WT-1*		*225 KW WT-2*		*KWH*		*KWH*	*Tot. KWH*
Date	*Fuel*	*Lube*	*Fuel*	*Lube*	*Time*	*Load*	*PF*	*DE-1*	*DE-2*	*DE-3*	*DE-4*	*Daily*	*CUM*	*Daily*	*CUM*	*Daily*	*CUM*	*Daily*	*Daily*
																			0
Jan-98																			0
Feb-98			42580	496.9									38122		57757		510068		605947
Mar-98			45250	387.4									37839		44341		520800		602980
Apr-98			43710	309.9									46161		44819		531300		622280
May-98			40940	287									53621		52120		496300		602041
Jun-98			41780	282									49255		46972		495600		591827
Jul-98			45251	289.5									31481		29385		542150		603016
Aug-98			48700	285									23649		21977		584850		630476
Sep-98			45736	585									23594		22423		555778		601795
Oct-98			48441	360.5									20356		19511		563150		603017
Nov-98			51180	528									32155		27362		607600		667117
Dec-98			55380	373.7									29516		33522		645400		708438
Jan-99			54680	453.6									28982		30333		634550		693865
Totals			563628	4638.5									414731		430522		6687546		7532799
MONTHLY TOTAL KWH PRODUCED																			**7532799**
DIESEL KWH PRODUCED PER GAL OF FUEL																			**11.87**
% WIND TURBINE KWH PRODUCED TO TOTAL GRID																			**11.22%**
FUEL SAVINGS BY WIND TURBINE OPERATIONS IN GALLONS (AVOIDED GALLONS USED)																			**71238**
						WT#1		WT#2		Total			Total						
										WTs			Diesel						
						38122		57757		95879			510068						
						37839		44341		82180			520800						
						46161		44819		90980			531300						
						53621		52120		105741			496300						
						49255		46972		96227			495600						
						31481		29385		60866			542150						
						23649		21977		45626			584850						
						23594		22423		46017			555778						
						20356		19511		39867			563150						
						32155		27362		59517			607600						
						29516		33522		63038			645400						
						28982		30333		59315			634550						

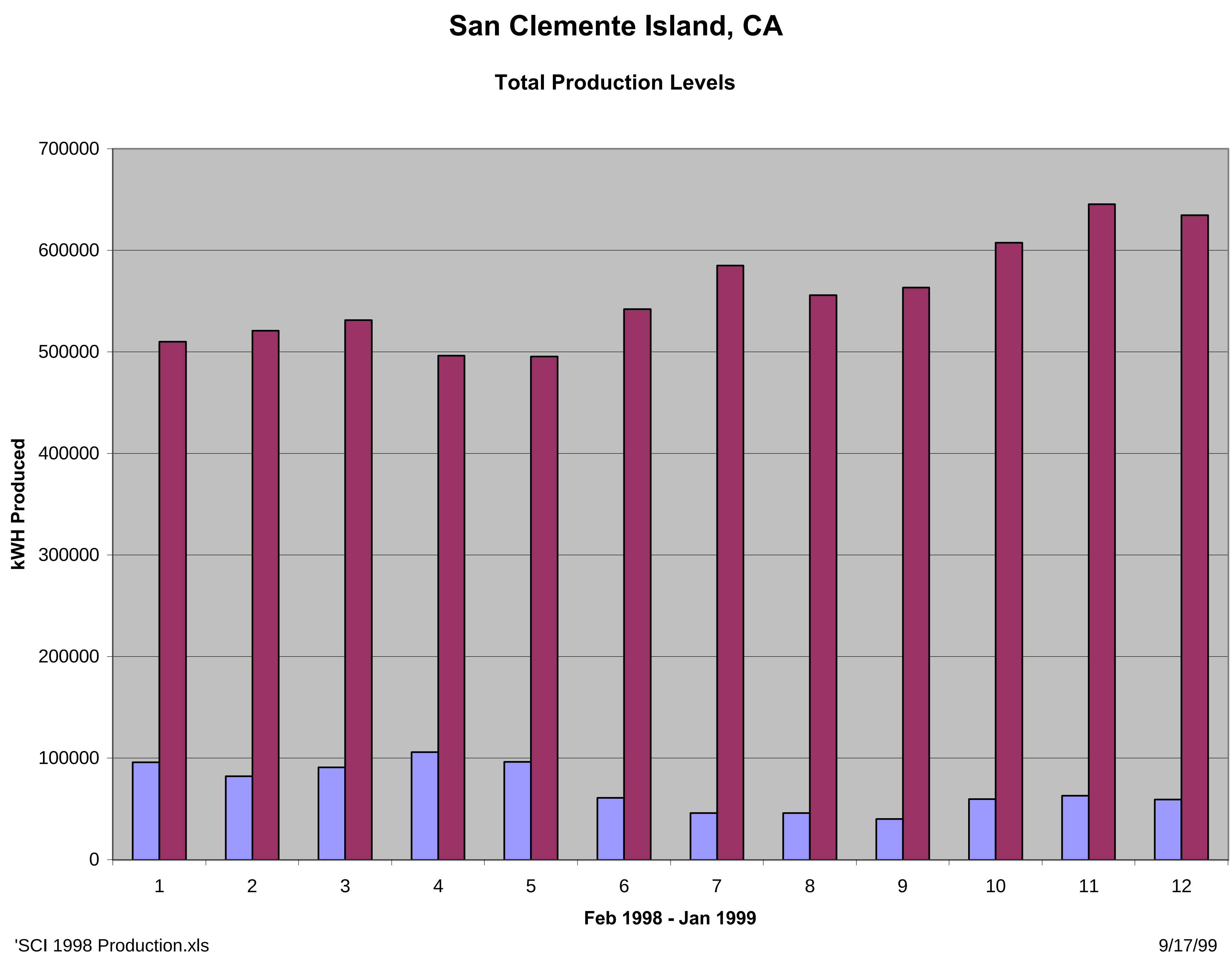
This Spreadsheet only shows 11 months of Wind Turbine Production
Of which Feb-Mar 98 were initial shakedown - limited production

'SCI 1998 Production.xls

9/17/99

San Clemente Island, California




San Clemente Island, CA
Total Production Levels
kWH Produced
700000
600000
500000
400000
300000
200000
100000
0
1
2
3
4
5
6
7
8
9
10
11
12
Feb 1998 - Jan 1999
'SCI 1998 Production.xls
9/17/99

February 1998

SCI Power Plant Production Report																			
	Fuel & Lube Oil Used								Diesel Generators			Wind Turbines				Total Diesel		Tot. WT	Grid Load
	Daily		Total		Daily Pk Demand		Avg	500 KW	500 KW	1.2 MW	750 KW	225 KW WT-1		225 KW WT-2		KWH		KWH	Tot. KWH
Date	Fuel	Lube	Fuel	Lube	Time	Load	PF	DE-1	DE-2	DE-3	DE-4	Daily	CUM	Daily	CUM	Daily	CUM	Daily	Daily
1-Feb	1600	0.0	1600	0	700	878	93	0	8400	0	8750	0	0	1682	1682	17150	17150	1682	18832
2-Feb	1630	68.4	3230	68.4	900	866	93	0	8400	0	10500	0	0	1682	3364	18900	36050	1682	20582
3-Feb	1690	222.6	4920	291	1800	1032	95	6300	0	0	14000	0	0	2841	6205	20300	56350	2841	23141
4-Feb	1810	0.0	6730	291	2100	655	94	9450	0	0	12250	46	46	292	6497	21700	78050	338	22038
5-Feb	1880	0.0	8610	291	800	470	96	8400	0	0	14000	158	204	69	6566	22400	100450	227	22627
6-Feb	1470	0.0	10080	291	1200	805	87	4200	0	0	14000	1925	2129	2546	9112	18200	118650	4471	22671
7-Feb	1310	0.0	11390	291	200	788	88	1050	0	0	14000	2017	4146	2358	11470	15050	133700	4375	19425
8-Feb	1480	0.0	12870	291	1800	756	92	4200	0	0	14000	1161	5307	1617	13087	18200	151900	2778	20978
9-Feb	1260	0.0	14130	291	1800	721	84	2100	0	0	14000	2806	8113	2792	15879	16100	168000	5598	21698
10-Feb	1970	0.0	16100	291	2000	1027	94	6300	0	5600	8750	139	8252	150	16029	20650	188650	289	20939
11-Feb	1810	0.0	17910	291	700	1023	94	3150	0	23400	0	457	8709	465	16494	25550	214200	922	27472
12-Feb	1780	28.2	19690	319.2	615	1235	94	0	3150	16800	0	939	9648	898	17392	19950	234150	1837	21787
13-Feb	1550	15.0	21240	334.2	600	1200	93	2100	0	16800	0	1928	11576	1854	19246	18900	253050	3782	22682
14-Feb	1420	0.0	22660	334.2	500	922	92	1050	0	16800	0	1159	12735	3794	23040	17850	270900	4953	22803
15-Feb	1460	19.7	24120	353.9	2200	880	92	0	0	16800	0	0	12735	4197	27237	16800	287700	4197	20997
16-Feb	1610	0.0	25730	353.9	400	1035	94	0	1050	19600	0	390	13125	760	27997	20650	308350	1150	21800
17-Feb	1410	15.4	27140	369.3	300	941	89	0	0	16800	0	2352	15477	4047	32044	16800	325150	6399	23199
18-Feb	1540	0.0	28680	369.3	600	1074	90	0	2100	16800	0	1432	16909	1659	33703	18900	344050	3091	21991
19-Feb	1630	15.0	30310	384.3	630	1108	94	0	2100	19600	0	1051	17960	1082	34785	21700	365750	2133	23833
20-Feb	1310	44.0	31620	428.3	2200	876	90	0	1050	5600	7000	2802	20762	4514	39299	13650	379400	7316	20966
21-Feb	1330	0.0	32950	428.3	600	895	90	0	0	14000	0	2762	23524	2640	41939	14000	393400	5402	19402
22-Feb	1180	8.8	34130	437.1	600	898	88	0	0	2800	10500	2651	26175	2609	44548	13300	406700	5260	18560
23-Feb	1130	0.0	35260	437.1	700	995	88	0	1050	5600	10500	3818	29993	3758	48306	17150	423850	7576	24726
24-Feb	1340	13.2	36600	450.3	600	1141	88	0	0	14000	0	2619	32612	3733	52039	14000	437850	6352	20352
25-Feb	1430	0.0	38030	450.3	. 09:00	920	89	0	0	16800	0	2020	35385	2162	53424	16800	454650	4182	20982
26-Feb	1510	20.0	39540	470.3	19:00	844	88	0	3150	16800	0	2163	37548	3389	56813	19950	474600	5552	25502
27-Feb	1560	10.0	41100	480.3	07:00	946	91	0	1050	11200	3500	498	38046	878	57691	17126	491726	1376	17126
28-Feb	1480	16.6	42580	496.9	06:00	870	91	0	4200	0	14000	76	38122	66	57757	18342	510068	142	18342
MONTHLY TOTAL KWH PRODUCED																			**605947**
KWH PRODUCED PER GAL OF FUEL																			**11.98**
% WIND TURBINE KWH PRODUCED TO TOTAL GRID																			**15.82%**
FUEL SAVINGS BY WIND TURBINE OPERATIONS IN GALLONS (AVOIDED GALLONS USED)																			**8004**

The Wind Turbines first started shakedown operations on February 5, 1998
23 Days of Wind Turbine Production

MARCH 1998

San Clemente Island Diesel and Wind Turbine Power Plant Status and Production Report																			
	Fuel & Lube Oil Used							Diesel Generators				Wind Turbines				Total Diesel		'otal W CI Grid Loa	
	Daily		Total		Daily Pk Demand		Avg	500 KWH	500 KWH	1.2 MW	750 KWH	225 KWH WT-1		225 KWH WT-2		KWH		KWH	Total KWH
Date	Fuel	Lube	Fuel	Lube	Time	Load	PF	DE-1	DE-2	DE-3	DE-4	Daily	CUM	Daily	CUM	Daily	CUM	Daily	Daily
1-Mar	1380	0	1380	0.0	600	832	88	0	0	0	17500	941	941	867	867	17500	17500	1808	19308
2-Mar	1510	69.8	2890	69.8	800	836	91	3150	0	2800	10500	598	1539	561	1428	16450	33950	1159	17609
3-Mar	1460	0	4350	69.8	700	960	92	0	0	16800	0	1042	2581	1008	2436	16800	50750	2050	18850
4-Mar	1620	0	5970	69.8	1000	960	91	2100	0	19600	0	445	3026	421	2857	21700	72450	866	22566
5-Mar	1500	31	7470	100.8	600	1120	92	0	0	16800	0	1080	4106	1036	3893	16800	89250	2116	18916
6-Mar	940	0	8410	100.8	2400	590	83	0	0	0	10500	4941	9047	4858	8751	10500	99750	9799	20299
7-Mar	1350	0	9760	100.8	700	805	91	0	0	0	15750	834	9881	1027	9778	15750	115500	1861	17611
8-Mar	1310	0	11070	100.8	2300	855	91	0	0	0	15750	1144	11025	1062	10840	15750	131250	2206	17956
9-Mar	1540	0	12610	100.8	550	905	93	3150	0	5600	10500	126	11151	197	11037	19250	150500	323	19573
10-Mar	1460	0	14070	100.8	600	895	93	0	0	19600	0	400	11551	865	11902	19600	170100	1265	20865
11-Mar	1580	30	15650	130.8	1000	937	92	0	0	19600	0	104	11655	121	12023	19600	189700	225	19825
12-Mar	1530	0	17180	130.8	1800	935	93	0	0	19600	0	599	12254	613	12636	19600	209300	1212	20812
13-Mar	1570	25	18750	155.8	700	965	92	0	0	16800	0	445	12699	572	13208	16800	226100	1017	17817
14-Mar	1370	0	20120	155.8	700	938	93	0	0	16800	0	1555	14254	1593	14801	16800	242900	3148	19948
15-Mar	1470	20	21590	175.8	2000	860	93	0	3150	2800	10500	1332	15586	1235	16036	16450	259350	2567	19017
16-Mar	1710	0	23300	175.8	2100	968	94	0	8400	0	12250	417	16003	393	16429	20650	280000	810	21460
17-Mar	1780	20	25080	195.8	1800	1138	94	0	8400	0	12250	618	16621	602	17031	20650	300650	1220	21870
18-Mar	1680	0	26760	195.8	900	1089	93	2100	0	16800	3500	437	17058	434	17465	22400	323050	871	23271
19-Mar	1700	17.6	28460	213.4	1900	980	94	0	0	19600	0	105	17163	538	18003	19600	342650	643	20243
20-Mar	1420	35.2	29880	248.6	700	1044	93	0	0	8400	5250	1326	18489	1241	19244	13650	356300	2567	16217
21-Mar	1480	17.6	31360	266.2	905	500	93	0	0	8400	12250	717	19206	676	19920	20650	376950	1393	22043
22-Mar	1470	0	32830	266.2	1300	873	93	0	0	2800	14000	875	20081	844	20764	16800	393750	1719	18519
23-Mar	1500	0	34330	266.2	600	944	93	0	0	16800	3500	1149	21230	1208	21972	20300	414050	2357	22657
24-Mar	1540	0	35870	266.2	500	1095	92	0	0	16800	0	1226	22456	1129	23101	16800	430850	2355	19155
25-Mar	1630	15	37500	281.2	1300	1170	90	2100	0	16800	0	2212	24668	2138	25239	18900	449750	4350	23250
26-Mar	1130	29	38630	310.2	1000	650	79	0	0	14000	0	5003	29671	4864	30103	14000	463750	9867	23867
27-Mar	1140	13	39770	323.2	600	992	83	0	0	11200	0	3839	33510	3724	33827	11200	474950	7563	18763
28-Mar	1070	17.4	40840	340.6	900	985	79	0	0	11200	0	2723	36233	4827	38654	11200	486150	7550	18750
29-Mar	1240	11.4	42080	352.0	2100	824	90	0	0	16800	0	0	36233	3766	42420	16800	502950	3766	20566
30-Mar	1500	35.4	43580	387.4	2200	955	95	0	0	16800	0	0	36233	235	42655	16800	519750	235	17035
31-Mar	1670	0	45250	387.4	1900	1215	92	1050	1050	19600	0	1606	37839	1686	44341	1050	520800	3292	24992

MONTHLY TOTAL KWH PRODUCED	**602980**
DIESEL KWH PRODUCED PER GAL OF FUEL	**11.51**
% WIND TURBINE KWH PRODUCED TO TOTAL GRID	**13.63%**
FUEL SAVINGS BY WIND TURBINE OPERATIONS IN GALLONS (AVOIDED GALLONS USED)	**7140**

APRIL 1998

SCI Power Plant Production Report																			
	Fuel & Lube Oil Used								Diesel Generators			Wind Turbines				Total Diesel		Tot. WT	Grid Load
	Daily		Total		Daily Pk Demand		Avg	500 KW	500 KW	1.2 MW	750 KW	225 KW WT-1		225 KW WT-2		KWH		KWH	Tot. KWH
Date	Fuel	Lube	Fuel	Lube	Time	Load	PF	DE-1	DE-2	DE-3	DE-4	Daily	CUM	Daily	CUM	Daily	CUM	Daily	Daily
1-Apr	1670	13.5	1670	13.5	2000	1019	92	4200	0	14000	0	2094	2094	2062	2062	18200	18200	4156	22356
2-Apr	1730	0	3400	13.5	900	1030	96	1050	0	22400	0	160	2254	164	2226	23450	41650	324	23774
3-Apr	1630	13.6	5030	27.1	2400	879	95	1050	0	8400	7000	726	2980	737	2963	16450	58100	1463	17913
4-Apr	1450	0	6480	27.1	2400	902	93	1050	0	0	17500	491	3471	480	3443	18550	76650	971	19521
5-Apr	1330	0	7810	27.1	500	836	83	1050	0	0	15750	1403	4874	1358	4801	16800	93450	2761	19561
6-Apr	1110	0	8920	27.1	2100	690	84	0	0	0	12250	4202	9076	4114	8915	12250	105700	8316	20566
7-Apr	1190	7.9	10110	35.0	700	917	85	0	0	11200	5250	4183	13259	4097	13012	16450	122150	8280	24730
8-Apr	1700	23.7	11810	58.7	500	1082	96	4200	0	16800	0	1454	14713	1417	14429	21000	143150	2871	23871
9-Apr	1590	20	13400	78.7	800	972	94	2100	0	16800	0	937	15650	883	15312	18900	162050	1820	20720
10-Apr	1270	18	14670	96.7	2000	847	94	0	3150	8400	1750	2451	18101	2420	17732	13300	175350	4871	18171
11-Apr	1310	0	15980	96.7	600	881	94	0	1050	0	14000	4986	23087	4722	22454	15050	190400	9708	24758
12-Apr	920	26.5	16900	123.2	1900	895	85	0	0	0	8750	4591	27678	4482	26936	8750	199150	9073	17823
13-Apr	1480	0	18380	123.2	1900	972	90	0	6300	0	14000	1949	29627	1913	28849	20300	219450	3862	24162
14-Apr	1700	35	20080	158.2	1000	975	91	0	8400	0	10500	1316	30943	1255	30104	18900	238350	2571	21471
15-Apr	1290	0	21370	158.2	2400	875	90	0	4200	8400	5250	4441	35384	4497	34601	17850	256200	8938	26788
16-Apr	1660	0	23030	158.2	700	1068	95	0	2100	19600	0	653	36037	619	35220	21700	277900	1272	22972
17-Apr	1490	61.6	24520	219.8	630	1038	93	0	0	11200	5250	315	36352	424	35644	16450	294350	739	17189
18-Apr	1410	0	25930	219.8	700	907	94	0	0	11200	8750	516	36868	291	35935	19950	314300	807	20757
19-Apr	1340	0	27270	219.8	630	820	93	0	0	0	15750	596	37464	520	36455	15750	330050	1116	16866
20-Apr	1490	0	28760	219.8	600	874	94	0	0	14000	5250	298	37762	269	36724	19250	349300	567	19817
21-Apr	1540	0	30300	219.8	2000	915	94	0	0	19600	0	153	37915	148	36872	19600	368900	301	19901
22-Apr	1640	22.5	31940	242.3	700	1040	95	0	0	19600	0	135	38050	139	37011	19600	388500	274	19874
23-Apr	1540	0	33480	242.3	620	1060	94	0	0	19600	0	475	38525	467	37478	19600	408100	942	20542
24-Apr	1220	0	34700	242.3	2100	943	95	0	0	5600	5250	2282	40807	2238	39716	10850	418950	4520	15370
25-Apr	1150	0	35850	242.3	700	1038	95	0	0	0	14000	2682	43489	2646	42362	14000	432950	5328	19328
26-Apr	1510	25	37360	267.3	600	866	94	0	5250	0	12250	362	43851	333	42695	17500	450450	695	18195
27-Apr	1470	0	38830	267.3	2100	986	94	0	0	19600	0	553	44404	514	43209	19600	470050	1067	20667
28-Apr	1630	25	40460	292.3	800	1032	95	2100	0	19600	0	665	45069	595	43804	21700	491750	1260	22960
29-Apr	1610	0	42070	292.3	900	1071	94	1050	0	19600	0	846	45915	767	44571	20650	512400	1613	22263
30-Apr	1640	17.6	43710	309.9	550	1075	94	2100	0	16800	0	246	46161	248	44819	18900	531300	494	19394
			43710										46161		44819		531300		

MONTHLY TOTAL KWH PRODUCED	**622280**
DIESEL KWH PRODUCED PER GAL OF FUEL	**12.16**
% WIND TURBINE KWH PRODUCED TO TOTAL GRID	**14.62%**
FUEL SAVINGS BY WIND TURBINE OPERATIONS IN GALLONS (AVOIDED GALLONS USED)	**7485**

April 11th - Off line for current assymetry (Phase Imbalance)
April 17th - Power Outage due to truck hitting power pole

MAY 1998

SCI Power Plant Production Report																			
	Fuel & Lube Oil Used								Diesel Generators			Wind Turbines				Total Diesel		Tot. WT	Grid Load
	Daily		Total		Daily Pk Demand		Avg	500 KW	500 KW	1.2 MW	750 KW	225 KW WT-1		225 KW WT-2		KWH		KWH	Tot. KWH
Date	Fuel	Lube	Fuel	Lube	Time	Load	PF	DE-1	DE-2	DE-3	DE-4	Daily	CUM	Daily	CUM	Daily	CUM	Daily	Daily
1-May	1470	4.4	1470	4.4	700	905	94	0	0	14000	5250	356	356	382	382	19250	19250	738	19988
2-May	1270	0	2740	4.4	1100	760	94	0	0	0	14000	1084	1440	1098	1480	14000	33250	2182	16182
3-May	1300	8.8	4040	13.2	700	775	94	0	0	0	17500	567	2007	597	2077	17500	50750	1164	18664
4-May	1330	39.9	5370	53.1	635	860	94	0	0	11200	5250	1048	3055	1039	3116	16450	67200	2087	18537
5-May	1330	0	6700	53.1	2100	950	94	0	0	16800	0	1597	4652	1627	4743	16800	84000	3224	20024
6-May	1510	0	8210	53.1	900	1068	95	0	0	16800	0	604	5256	606	5349	16800	100800	1210	18010
7-May	1270	14	9480	67.1	600	912	95	0	0	11200	3500	2101	7357	2042	7391	14700	115500	4143	18843
8-May	1010	0	10490	67.1	700	931	93	0	0	0	12250	3378	10735	3303	10694	12250	127750	6681	18931
9-May	1100	10	11590	77.1	800	904	93	0	0	0	14000	2698	13433	2606	13300	14000	141750	5304	19304
10-May	1180	0	12770	77.1	2300	895	95	0	0	0	14000	2505	15938	2435	15735	14000	155750	4940	18940
11-May	1180	20	13950	97.1	2300	852	94	0	1050	0	12250	2934	18872	2875	18610	13300	169050	5809	19109
12-May	1420	15	15370	112.1	1900	1020	93	0	1050	11200	3500	2266	21138	2288	20898	15750	184800	4554	20304
13-May	1200	4.4	16570	116.5	2200	790	89	0	0	16800	0	2386	23524	2352	23250	16800	201600	4738	21538
14-May	1350	28	17920	144.5	500	878	90	0	0	16800	0	1807	25331	1727	24977	16800	218400	3534	20334
15-May	1290	0	19210	144.5	700	854	91	0	0	11200	5250	1452	26783	1360	26337	16450	234850	2812	19262
16-May	1090	0	20300	144.5	700	797	81	0	0	0	14000	2454	29237	2418	28755	14000	248850	4872	18872
17-May	1190	1.5	21490	146.0	700	812	90	0	0	0	14000	1707	30944	1732	30487	14000	262850	3439	17439
18-May	1400	0	22890	146.0	700	838	91	0	0	14000	3500	809	31753	743	31230	17500	280350	1552	19052
19-May	1430	0	24320	146.0	1500	825	92	0	0	16800	0	1289	33042	1206	32436	16800	297150	2495	19295
20-May	1450	22	25770	168.0	2200	1004	93	0	0	16800	0	2003	35045	1914	34350	16800	313950	3917	20717
21-May	1460	0	27230	168.0	2300	1088	94	0	0	19600	0	1727	36772	1665	36015	19600	333550	3392	22992
22-May	1360	18	28590	186.0	600	1037	94	0	0	14000	0	2127	38899	2035	38050	14000	347550	4162	18162
23-May	1400	20	29990	206.0	700	895	93	3150	0	0	12250	1361	40260	1286	39336	15400	362950	2647	18047
24-May	1390	20	31380	226.0	2400	938	93	4200	0	0	14000	1461	41721	1405	40741	18200	381150	2866	21066
25-May	1210	0	32590	226.0	600	979	94	0	0	0	14000	2397	44118	2301	43042	14000	395150	4698	18698
26-May	1150	20	33740	246.0	1900	930	93	0	0	2800	12250	3620	47738	3512	46554	15050	410200	7132	22182
27-May	1450	0	35190	246.0	2200	852	93	1050	0	16800	0	1404	49142	1325	47879	17850	428050	2729	20579
28-May	1550	10	36740	256.0	1400	830	93	1050	0	16800	0	806	49948	732	48611	17850	445900	1538	19388
29-May	1280	0	38020	256.0	600	786	89	0	0	14000	0	2616	52564	2531	51142	14000	459900	5147	19147
30-May	1430	31	39450	287.0	2300	849	93	0	0	19600	0	724	53288	672	51814	19600	479500	1396	20996
31-May	1490	0	40940	287.0	600	873	92	0	0	16800	0	333	53621	306	52120	16800	496300	639	17439

MONTHLY TOTAL KWH PRODUCED	**602041**
DIESEL KWH PRODUCED PER GAL OF FUEL	**12.12**
% WIND TURBINE KWH PRODUCED TO TOTAL GRID	**17.56%**
FUEL SAVINGS BY WIND TURBINE OPERATIONS IN GALLONS (AVOIDED GALLONS USED)	**8723**

JUNE 1998

SCI Power Plant Production Report																			
	Fuel & Lube Oil Used							Diesel Generators				Wind Turbines				Total Diesel		Tot. WT	Grid Load
	Daily		Total		Daily Pk Demand		Avg	500 KW	500 KW	1.2 MW	750 KW	225 KW WT-1		225 KW WT-2		KWH		KWH	Tot. KWH
Date	Fuel	Lube	Fuel	Lube	Time	Load	PF	DE-1	DE-2	DE-3	DE-4	Daily	CUM	Daily	CUM	Daily	CUM	Daily	Daily
1-Jun	1430	0	1430	0.0	700	866	93	0	0	19600	0	1277	1277	1193	1193	19600	19600	2470	22070
2-Jun	1170	26.4	2600	26.4	200	649	87	0	0	11200	0	3891	5168	3730	4923	11200	30800	7621	18821
3-Jun	1390	0	3990	26.4	1400	997	90	0	0	16800	0	2659	7827	2537	7460	16800	47600	5196	21996
4-Jun	1460	20	5450	46.4	700	944	91	1050	0	16800	0	1973	9800	1889	9349	17850	65450	3862	21712
5-Jun	1250	0	6700	46.4	600	1009	88	0	0	16800	0	2646	12446	2541	11890	16800	82250	5187	21987
6-Jun	1320	25	8020	71.4	1100	922	92	0	0	14000	0	1781	14227	1719	13609	14000	96250	3500	17500
7-Jun	1310	4.4	9330	75.8	2100	840	92	0	0	16800	0	1855	16082	1771	15380	16800	113050	3626	20426
8-Jun	1450	0	10780	75.8	1900	976	91	0	0	16800	0	1369	17451	1327	16707	16800	129850	2696	19496
9-Jun	1700	22	12480	97.8	1100	1014	92	2100	0	16800	0	303	17754	269	16976	18900	148750	572	19472
10-Jun	1600	0	14080	97.8	700	1217	92	2100	0	16800	0	1218	18972	1155	18131	18900	167650	2373	21273
11-Jun	1430	13.2	15510	111.0	600	944	91	0	0	19600	0	1610	20582	1548	19679	19600	187250	3158	22758
12-Jun	1270	8.8	16780	119.8	2200	861	92	0	0	14000	0	749	21331	731	20410	14000	201250	1480	15480
13-Jun	1370	0	18150	119.8	700	834	91	0	0	16800	0	1624	22955	1591	22001	16800	218050	3215	20015
14-Jun	1380	0	19530	119.8	1000	786	91	0	0	2800	10500	1766	24721	1646	23647	13300	231350	3412	16712
15-Jun	1550	0	21080	119.8	700	878	90	0	5250	0	12250	923	25644	890	24537	17500	248850	1813	19313
16-Jun	1660	0	22740	119.8	700	971	94	0	7350	0	12250	468	26112	453	24990	19600	268450	921	20521
17-Jun	1730	30.8	24470	150.6	700	1092	95	0	8400	0	12250	526	26638	523	25513	20650	289100	1049	21699
18-Jun	1650	17.6	26120	168.2	2100	915	93	0	8400	0	12250	210	26848	199	25712	20650	309750	409	21059
19-Jun	1530	13.2	27650	181.4	900	906	93	0	5250	0	12250	784	27632	745	26457	17500	327250	1529	19029
20-Jun	1240	0	28890	181.4	1400	712	91	0	0	0	14000	1354	28986	1296	27753	14000	341250	2650	16650
21-Jun	1220	0	30110	181.4	1600	830	92	0	0	0	15750	1687	30673	1650	29403	15750	357000	3337	19087
22-Jun	1340	50	31450	231.4	2200	845	91	0	0	16800	1750	1497	32170	1447	30850	18550	375550	2944	21494
23-Jun	1330	4.4	32780	235.8	800	929	89	0	0	14000	0	2050	34220	1956	32806	14000	389550	4006	18006
24-Jun	1390	0	34170	235.8	1100	905	90	0	0	16800	0	1652	35872	1605	34411	16800	406350	3257	20057
25-Jun	1380	0	35550	235.8	1400	860	90	0	0	16800	0	1599	37471	1519	35930	16800	423150	3118	19918
26-Jun	1330	22.2	36880	258.0	1000	870	90	0	0	11200	3500	1634	39105	1538	37468	14700	437850	3172	17872
27-Jun	1360	0	38240	258.0	2100	880	90	0	0	0	15750	1184	40289	1099	38567	15750	453600	2283	18033
28-Jun	1250	24	39490	282.0	2100	840	91	0	0	0	14000	2121	42410	1965	40532	14000	467600	4086	18086
29-Jun	1180	0	40670	282.0	1900	920	90	0	0	0	14000	3082	45492	2921	43453	14000	481600	6003	20003
30-Jun	1110	0	41780	282.0	700	940	91	0	0	0	14000	3763	49255	3519	46972	14000	495600	7282	21282
			41780										49255		46972		495600		

MONTHLY TOTAL KWH PRODUCED	**591827**
DIESEL KWH PRODUCED PER GAL OF FUEL	**11.86**
% WIND TURBINE KWH PRODUCED TO TOTAL GRID	**16.26%**
FUEL SAVINGS BY WIND TURBINE OPERATIONS IN GALLONS (AVOIDED GALLONS USED)	**8112**

June 12th - D-Line Down

JULY 1998

SCI Power Plant Production Report																			
	Fuel & Lube Oil Used								Diesel Generators			Wind Turbines				Total Diesel		Tot. WT	Grid Load
	Daily		Total		Daily Pk Demand		Avg	500 KW	500 KW	1.2 MW	750 KW	225 KW WT-1		225 KW WT-2		KWH		KWH	Tot. KWH
Date	Fuel	Lube	Fuel	Lube	Time	Load	PF	DE-1	DE-2	DE-3	DE-4	Daily	CUM	Daily	CUM	Daily	CUM	Daily	Daily
1-Jul	1430	0	1430	0.0	800	939	90	0	4200	0	12250	2406	2406	2265	2265	16450	16450	4671	21121
2-Jul	1140	0	2570	0.0	800	743	90	0	1050	0	14000	2958	5364	2795	5060	15050	31500	5753	20803
3-Jul	1240	13	3810	13.0	2300	718	90	0	0	0	14000	1369	6733	1315	6375	14000	45500	2684	16684
4-Jul	1390	11.6	5200	24.6	530	846	93	0	0	0	15750	329	7062	302	6677	15750	61250	631	16381
5-Jul	1410	0	6610	24.6	2400	780	93	0	0	0	17500	300	7362	268	6945	17500	78750	568	18068
6-Jul	1560	20	8170	44.6	2100	850	93	0	4200	0	14000	382	7744	347	7292	18200	96950	729	18929
7-Jul	1520	0	9690	44.6	700	811	94	0	6300	0	10500	849	8593	773	8065	16800	113750	1622	18422
8-Jul	1530	23	11220	67.6	1100	914	93	0	4200	11200	7000	1060	9653	1008	9073	22400	136150	2068	24468
9-Jul	1360	0	12580	67.6	600	849	91	0	0	16800	0	1376	11029	1245	10318	16800	152950	2621	19421
10-Jul	1220	14	13800	81.6	600	760	0	0	0	5600	7000	2190	13219	1989	12307	12600	165550	4179	16779
11-Jul	1170	0	14970	81.6	900	758	88	0	0	0	14000	2192	15411	2006	14313	14000	179550	4198	18198
12-Jul	1410	0	16380	81.6	600	804	92	0	0	0	15750	442	15853	417	14730	15750	195300	859	16609
13-Jul	1500	0	17880	81.6	2000	845	93	0	0	11200	7000	27	15880	24	14754	18200	213500	51	18251
14-Jul	1550	0	19430	81.6	800	875	92	0	0	19600	0	219	16099	212	14966	19600	233100	431	20031
15-Jul	1690	19	21120	100.6	600	999	94	0	1050	16800	3500	129	16228	128	15094	21350	254450	257	21607
16-Jul	1640	30	22760	130.6	1200	968	93	0	0	19600	0	52	16280	48	15142	19600	274050	100	19700
17-Jul	1600	0	24360	130.6	900	956	92	0	0	19600	0	96	16376	110	15252	19600	293650	206	19806
18-Jul	1510	15	25870	145.6	2100	923	92	0	0	19600	0	288	16664	313	15565	19600	313250	601	20201
19-Jul	1530	11.4	27400	157.0	2300	883	92	0	0	19600	0	101	16765	113	15678	19600	332850	214	19814
20-Jul	1660	0	29060	157.0	2100	906	93	0	3150	14000	2100	168	16933	165	15843	19250	352100	333	19583
21-Jul	1660	0	30720	157.0	800	883	92	0	8400	0	10500	488	17421	467	16310	18900	371000	955	19855
22-Jul	1750	8.4	32470	165.4	1100	1095	93	0	8400	0	12250	212	17633	202	16512	20650	391650	414	21064
23-Jul	1681	0	34151	165.4	600	979	90	4200	5250	0	10500	400	18033	382	16894	19950	411600	782	20732
24-Jul	1460	35.6	35611	201.0	1000	935	92	4200	0	0	14000	753	18786	705	17599	18200	429800	1458	19658
25-Jul	1330	0	36941	201.0	2300	837	87	0	0	0	14000	1243	20029	1136	18735	14000	443800	2379	16379
26-Jul	1190	0	38131	201.0	2100	861	88	0	0	0	14000	2623	22652	2392	21127	14000	457800	5015	19015
27-Jul	1420	18.5	39551	219.5	2100	969	90	0	0	14000	2100	1583	24235	1460	22587	16100	473900	3043	19143
28-Jul	1550	0	41101	219.5	1200	1083	92	0	0	19600	0	848	25083	792	23379	19600	493500	1640	21240
29-Jul	1380	25	42481	244.5	1300	1100	92	1050	0	14000	0	2931	28014	2778	26157	15050	508550	5709	20759
30-Jul	1350	0	43831	244.5	1200	1041	93	0	0	16800	0	2277	30291	2147	28304	16800	525350	4424	21224
31-Jul	1420	45	45251	289.5	1100	922	93	0	0	16800	0	1190	31481	1081	29385	16800	542150	2271	19071

MONTHLY TOTAL KWH PRODUCED	**603016**
DIESEL KWH PRODUCED PER GAL OF FUEL	**11.98**
% WIND TURBINE KWH PRODUCED TO TOTAL GRID	**10.09%**
FUEL SAVINGS BY WIND TURBINE OPERATIONS IN GALLONS (AVOIDED GALLONS USED)	**5080**

AUGUST 1998

SCI Power Plant Production Report																			
	Fuel & Lube Oil Used							*Diesel Generators*				*Wind Turbines*				*Total Diesel*		*Tot. WT*	*Grid Load*
	Daily		*Total*		*Daily Pk Demand*		*Avg*	*500 KW*	*500 KW*	*1.2 MW*	*750 KW*	*225 KW WT-1*		*225 KW WT-2*		*KWH*		*KWH*	*Tot. KWH*
Date	*Fuel*	*Lube*	*Fuel*	*Lube*	*Time*	*Load*	*PF*	*DE-1*	*DE-2*	*DE-3*	*DE-4*	*Daily*	*CUM*	*Daily*	*CUM*	*Daily*	*CUM*	*Daily*	*Daily*
1-Aug	1540	0	1540	0.0	2100	866	93	3150	0	0	15750	293	293	273	273	18900	18900	566	19466
2-Aug	1590	0	3130	0.0	2200	918	93	6300	0	0	14000	313	606	270	543	20300	39200	583	20883
3-Aug	1440	13	4570	13.0	2300	932	92	0	0	14000	3500	1068	1674	976	1519	17500	56700	2044	19544
4-Aug	1570	0	6140	13.0	700	1045	92	2100	0	16800	0	1157	2831	1318	2837	18900	75600	2475	21375
5-Aug	1680	0	7820	13.0	1100	968	92	3150	0	19600	0	800	3631	586	3423	22750	98350	1386	24136
6-Aug	1520	17.6	9340	30.6	1100	933	93	0	0	16800	0	1036	4667	962	4385	16800	115150	1998	18798
7-Aug	1620	13.2	10960	43.8	800	971	93	0	0	19600	0	423	5090	391	4776	19600	134750	814	20414
8-Aug	1620	17.6	12580	61.4	600	964	93	3150	0	14000	1750	176	5266	169	4945	18900	153650	345	19245
9-Aug	1580	0	14160	61.4	2100	922	93	0	0	19600	0	16	5282	13	4958	19600	173250	29	19629
10-Aug	1700	0	15860	61.4	1600	1014	93	1050	0	19600	0	221	5503	211	5169	20650	193900	432	21082
11-Aug	1900	17.6	17760	79.0	1100	1064	93	4200	0	16800	0	633	6136	580	5749	21000	214900	1213	22213
12-Aug	1790	14	19550	93.0	800	1046	91	4200	0	14000	0	1020	7156	928	6677	18200	233100	1948	20148
13-Aug	1600	10	21150	103.0	700	986	91	3150	0	16800	0	2019	9175	1880	8557	19950	253050	3899	23849
14-Aug	1540	30	22690	133.0	900	1006	90	3150	0	14000	0	889	10064	842	9399	17150	270200	1731	18881
15-Aug	1450	0	24140	133.0	1200	812	93	0	0	19600	0	130	10194	131	9530	19600	289800	261	19861
16-Aug	1430	15	25570	148.0	2000	827	93	0	0	16800	0	0	10194	0	9530	16800	306600	0	16800
17-Aug	1500	20	27070	168.0	2000	908	92	1050	0	16800	0	771	10965	719	10249	17850	324450	1490	19340
18-Aug	1520	28.6	28590	196.6	1700	998	89	3150	0	14000	0	1440	12405	1353	11602	17150	341600	2793	19943
19-Aug	1360	0	29950	196.6	1300	1050	92	2100	0	14000	0	2839	15244	2666	14268	16100	357700	5505	21605
20-Aug	1440	13.2	31390	209.8	2000	900	91	1050	0	11200	5250	1222	16466	1115	15383	17500	375200	2337	19837
21-Aug	1460	0	32850	209.8	1000	840	92	4200	0	0	12250	865	17331	764	16147	16450	391650	1629	18079
22-Aug	1380	0	34230	209.8	600	840	93	0	0	2800	15750	940	18271	844	16991	18550	410200	1784	20334
23-Aug	1580	0	35810	209.8	1600	890	92	1050	0	8400	10500	58	18329	53	17044	19950	430150	111	20061
24-Aug	1560	19.8	37370	229.6	1900	1015	93	0	0	16800	0	216	18545	216	17260	16800	446950	432	17232
25-Aug	1590	0	38960	229.6	1700	980	91	0	0	22400	0	345	18890	330	17590	22400	469350	675	23075
26-Aug	1520	14	40480	243.6	900	934	93	1050	0	16800	0	1073	19963	1073	18663	17850	487200	2146	19996
27-Aug	1570	16	42050	259.6	1200	958	93	2100	0	16800	0	1252	21215	1152	19815	18900	506100	2404	21304
28-Aug	1490	0	43540	259.6	800	988	92	0	0	19600	0	1338	22553	1181	20996	19600	525700	2519	22119
29-Aug	1700	15.4	45240	275.0	2000	951	92	0	6300	5600	8750	149	22702	121	21117	20650	546350	270	20920
30-Aug	1670	0	46910	275.0	1400	910	93	0	7350	0	10500	469	23171	429	21546	17850	564200	898	18748
31-Aug	1790	10	48700	285.0	2000	966	93	0	8400	0	12250	478	23649	431	21977	20650	584850	909	21559

MONTHLY TOTAL KWH PRODUCED	**630476**
DIESEL KWH PRODUCED PER GAL OF FUEL	**12.01**
% WIND TURBINE KWH PRODUCED TO TOTAL GRID	**7.24%**
FUEL SAVINGS BY WIND TURBINE OPERATIONS IN GALLONS (AVOIDED GALLONS USED)	**3799**

August 4th - 1600Hr Heavy Loads tripped Power Plant off line
August 5th - Wind Turbines off line for Maintenance

SEPTEMBER 1998

SCI Power Plant Production Report																			
	Fuel & Lube Oil Used								Diesel Generators				Wind Turbines				Total Diesel		Tot. WT	Grid Load
	Daily		Total		Daily Pk Demand		Avg	500 KW	500 KW	1.2 MW	750 KW	225 KW WT-1		225 KW WT-2		KWH		KWH	Tot. KWH
Date	Fuel	Lube	Fuel	Lube	Time	Load	PF	DE-1	DE-2	DE-3	DE-4	Daily	CUM	Daily	CUM	Daily	CUM	Daily	Daily
1-Sep	1770	248	1770	248.0	2200	966	93	0	8400	0	12250	663	663	592	592	20650	20650	1255	21905
2-Sep	1840	0	3610	248.0	1200	1050	93	0	9450	0	14000	338	1001	314	906	23450	44100	652	24102
3-Sep	1750	0	5360	248.0	1100	988	92	0	5250	11200	3500	301	1302	307	1213	19950	64050	608	20558
4-Sep	1550	0	6910	248.0	1100	929	93	0	0	11200	7000	122	1424	127	1340	18200	82250	249	18449
5-Sep	1440	0	8350	248.0	900	778	93	0	0	0	17500	105	1529	101	1441	17500	99750	206	17706
6-Sep	1440	17	9790	265.0	1500	840	92	0	0	0	17500	199	1728	199	1640	17500	117250	398	17898
7-Sep	1450	0	11240	265.0	2000	817	0	0	0	0	17500	165	1893	155	1795	17500	134750	320	17820
8-Sep	1560	60	12800	325.0	2000	905	92	0	0	14000	5250	191	2084	173	1968	19250	154000	364	19614
9-Sep	1690	0	14490	325.0	1225	1065	93	3150	0	16800	0	326	2410	312	2280	19950	173950	638	20588
10-Sep	1570	0	16060	325.0	1300	939	93	0	0	19600	0	550	2960	519	2799	19600	193550	1069	20669
11-Sep	1560	13	17620	338.0	1000	849	93	0	0	19600	0	170	3130	156	2955	19600	213150	326	19926
12-Sep	1440	20	19060	358.0	1000	800	93	0	0	16800	0	653	3783	576	3531	16800	229950	1229	18029
13-Sep	1440	15	20500	373.0	1000	814	93	0	0	18528	0	896	4679	832	4363	18528	248478	1728	20256
14-Sep	1510	18	22010	391.0	2000	856	93	0	0	19600	0	673	5352	613	4976	19600	268078	1286	20886
15-Sep	1470	0	23480	391.0	700	928	92	0	0	16800	0	1190	6542	1113	6089	16800	284878	2303	19103
16-Sep	1620	14	25100	405.0	1000	908	93	2100	0	16800	0	782	7324	711	6800	18900	303778	1493	20393
17-Sep	1480	0	26580	405.0	1000	1031	93	0	0	19600	0	920	8244	835	7635	19600	323378	1755	21355
18-Sep	1410	25	27990	430.0	1400	965	94	0	0	16800	0	1490	9734	1380	9015	16800	340178	2870	19670
19-Sep	1540	0	29530	430.0	2100	909	94	0	5250	0	12250	55	9789	35	9050	17500	357678	90	17590
20-Sep	1230	9	30760	439.0	2100	912	93	0	6300	0	14000	163	9952	172	9222	20300	377978	335	20635
21-Sep	1590	0	32350	439.0	2000	973	93	0	0	14000	3500	476	10428	451	9673	17500	395478	927	18427
22-Sep	1580	20	33930	459.0	2100	968	94	0	0	19600	0	514	10942	477	10150	19600	415078	991	20591
23-Sep	1610	20	35540	479.0	1200	1029	93	1050	0	16800	0	1136	12078	1112	11262	17850	432928	2248	20098
24-Sep	1500	35	37040	514.0	700	995	92	2100	0	16800	0	1850	13928	1726	12988	18900	451828	3576	22476
25-Sep	1350	10	38390	524.0	1200	935	89	0	0	16800	0	1758	15686	1702	14690	16800	468628	3460	20260
26-Sep	1370	0	39760	524.0	2000	888	91	0	0	14000	0	1062	16748	1038	15728	14000	482628	2100	16100
27-Sep	1500	18	41260	542.0	1900	866	92	0	0	19600	0	499	17247	451	16179	19600	502228	950	20550
28-Sep	1460	0	42720	542.0	1600	921	92	0	0	16800	0	1384	18631	1410	17589	16800	519028	2794	19594
29-Sep	1400	43	44120	585.0	2100	1013	88	0	0	16800	0	3530	22161	3472	21061	16800	535828	7002	23802
30-Sep	1616	0	45736	585.0	1100	959	92	3150	0	16800	0	1433	23594	1362	22423	19950	555778	2795	22745
			45736										23594		22423		555778		

MONTHLY TOTAL KWH PRODUCED 601795

DIESEL KWH PRODUCED PER GAL OF FUEL 12.15

% WIND TURBINE KWH PRODUCED TO TOTAL GRID 7.65%

FUEL SAVINGS BY WIND TURBINE OPERATIONS IN GALLONS (AVOIDED GALLONS USED) 3787

OCTOBER 1998

SCI Power Plant Production Report																			
	Fuel & Lube Oil Used							Diesel Generators				Wind Turbines				Total Diesel		Tot. WT	Grid Load
	Daily		Total		Daily Pk Demand		Avg	500 KW	500 KW	1.2 MW	750 KW	225 KW WT-1		225 KW WT-2		KWH		KWH	Tot. KWH
Date	Fuel	Lube	Fuel	Lube	Time	Load	PF	DE-1	DE-2	DE-3	DE-4	Daily	CUM	Daily	CUM	Daily	CUM	Daily	Daily
1-Oct	1560	0	1560	0.0	730	1053	93	1050	0	14000	0	1410	1410	1347	1347	15050	15050	2757	17807
2-Oct	1440	22	3000	22.0	1100	902	93	0	0	14000	3500	875	2285	849	2196	17500	32550	1724	19224
3-Oct	1330	0	4330	22.0	2405	900	92	0	0	5600	10500	1415	3700	1351	3547	16100	48650	2766	18866
4-Oct	1600	0	5930	22.0	2100	939	94	6300	0	0	14000	136	3836	137	3684	20300	68950	273	20573
5-Oct	1670	0	7600	22.0	2100	1008	93	2100	0	16800	1750	75	3911	73	3757	20650	89600	148	20798
6-Oct	1620	22	9220	44.0	1600	945	92	0	0	19600	0	227	4138	252	4009	19600	109200	479	20079
7-Oct	1710	13.7	10930	57.7	0000	980	92	2100	0	19600	0	582	4720	536	4545	21700	130900	1118	22818
8-Oct	1491	14	12421	71.7	0000	996	89	0	0	16800	0	1529	6249	1398	5943	16800	147700	2927	19727
9-Oct	1440	0	13861	71.7	600	975	90	0	0	16800	0	1155	7404	1053	6996	16800	164500	2208	19008
10-Oct	1530	20	15391	91.7	600	837	92	0	0	19600	0	113	7517	73	7069	19600	184100	186	19786
11-Oct	1520	15	16911	106.7	1100	940	92	0	0	16800	0	65	7582	70	7139	16800	200900	135	16935
12-Oct	1560	0	18471	106.7	1100	857	93	0	2100	11200	3500	60	7642	59	7198	16800	217700	119	16919
13-Oct	1700	0	20171	106.7	2100	961	97	0	7350	0	12250	526	8168	477	7675	19600	237300	1003	20603
14-Oct	1590	18.7	21761	125.4	1300	1035	93	0	7350	0	10500	2094	10262	2008	9683	17850	255150	4102	21952
15-Oct	1540	4.4	23301	129.8	800	1020	93	0	4200	0	14000	1766	12028	1660	11343	18200	273350	3426	21626
16-Oct	1610	37.3	24911	167.1	700	925	94	0	5250	0	14000	241	12269	245	11588	19250	292600	486	19736
17-Oct	1400	1	26311	168.1	2100	860	93	0	0	0	15750	504	12773	750	12338	15750	308350	1254	17004
18-Oct	1420	0	27731	168.1	2100	880	93	0	0	2800	14000	576	13349	589	12927	16800	325150	1165	17965
19-Oct	1530	33.1	29261	201.2	2000	905	93	0	0	19600	0	179	13528	161	13088	19600	344750	340	19940
20-Oct	1580	19.3	30841	220.5	2200	870	94	0	1050	14000	5250	139	13667	123	13211	20300	365050	262	20562
21-Oct	1800	20	32641	240.5	1100	990	940	3150	0	16800	0	260	13927	280	13491	19950	385000	540	20490
22-Oct	2010	0	34651	240.5	700	1007	94	3150	0	16800	0	343	14270	305	13796	19950	404950	648	20598
23-Oct	1540	25	36191	265.5	700	946	93	1050	0	16800	0	601	14871	509	14305	17850	422800	1110	18960
24-Oct	1360	15	37551	280.5	800	850	90	0	0	14000	0	1395	16266	1304	15609	14000	436800	2699	16699
25-Oct	1290	20	38841	300.5	2000	844	91	0	0	16800	0	1749	18015	1691	17300	16800	453600	3440	20240
26-Oct	1610	10	40451	310.5	1800	920	94	0	0	19600	0	259	18274	255	17555	19600	473200	514	20114
27-Oct	1730	0	42181	310.5	1800	961	94	1050	0	16800	0	516	18790	488	18043	17850	491050	1004	18854
28-Oct	1510	50	43691	360.5	0000	900	93	1050	0	16800	0	1566	20356	1468	19511	17850	508900	3034	20884
29-Oct	1590	0	45281	360.5	1800	888	93	0	5250	2800	8750	0	20356	0	19511	16800	525700	0	16800
30-Oct	1670	0	46951	360.5	700	855	94	0	8400	0	10500	0	20356	0	19511	18900	544600	0	18900
31-Oct	1490	0	48441	360.5	2000	830	93	0	2100	11200	5250	0	20356	0	19511	18550	563150	0	18550

MONTHLY TOTAL KWH PRODUCED — **603017**

DIESEL KWH PRODUCED PER GAL OF FUEL — **11.63**

% WIND TURBINE KWH PRODUCED TO TOTAL GRID — **6.61%**

FUEL SAVINGS BY WIND TURBINE OPERATIONS IN GALLONS (AVOIDED GALLONS USED) — **3429**

NOVEMBER 1998

SCI Power Plant Production Report																			
	Fuel & Lube Oil Used								Diesel Generators			Wind Turbines				Total Diesel		Tot. WT	Grid Load
	Daily		Total		Daily Pk Demand		Avg	500 KW	500 KW	1.2 MW	750 KW	225 KW WT-1		225 KW WT-2		KWH		KWH	Tot. KWH
Date	Fuel	Lube	Fuel	Lube	Time	Load	PF	DE-1	DE-2	DE-3	DE-4	Daily	CUM	Daily	CUM	Daily	CUM	Daily	Daily
1-Nov	1530	0	1530	0.0	1800	827	94	0	0	19600	0	0	0	0	0	19600	19600	0	19600
2-Nov	1650	0	3180	0.0	1700	1200	95	1050	0	19600	0	0	0	0	0	20650	40250	0	1610
3-Nov	1610	46	4790	46.0	700	1100	94	1050	0	19600	0	2011	2011	1829	1829	20650	60900	3840	24490
4-Nov	1670	0	6460	46.0	600	1038	94	3150	0	16800	0	3094	5105	2805	4634	19950	80850	5899	25849
5-Nov	1680	17.6	8140	63.6	600	982	94	2100	0	16800	0	1210	6315	1142	5776	18900	99750	2352	21252
6-Nov	1440	0	9580	63.6	700	921	94	0	0	16800	0	2235	8550	2291	8067	16800	116550	4526	21326
7-Nov	1550	27	11130	90.6	1800	938	94	2100	0	16800	0	1542	10092	1663	9730	18900	135450	3205	22105
8-Nov	1910	13.2	13040	103.8	1100	960	94	1050	0	16800	0	3842	13934	3694	13424	17850	153300	7536	25386
9-Nov	1590	53	14630	156.8	1900	1029	94	2100	0	14000	0	525	14459	694	14118	16100	169400	1219	17319
10-Nov	1880	0	16510	156.8	600	1150	94	5250	0	16800	0	347	14806	313	14431	22050	191450	660	22710
11-Nov	1970	0	18480	156.8	600	1089	94	7350	0	16800	0	296	15102	456	14887	24150	215600	752	24902
12-Nov	1790	25	20270	181.8	600	1059	95	4200	0	16800	0	360	15462	467	15354	21000	236600	827	21827
13-Nov	1660	25	21930	206.8	700	1025	95	1050	0	19600	0	354	15816	362	15716	20650	257250	716	21366
14-Nov	1580	15	23510	221.8	600	958	94	0	3150	0	15750	522	16338	468	16184	18900	276150	990	19890
15-Nov	1630	25	25140	246.8	2300	1053	95	0	5250	0	15750	741	17079	655	16839	21000	297150	1396	22396
16-Nov	1650	0	26790	246.8	2200	962	94	0	7350	0	12250	1194	18273	1138	17977	19600	316750	2332	21932
17-Nov	1780	10	28570	256.8	1800	1196	95	0	8400	0	12250	1475	19748	1424	19401	20650	337400	2899	23549
18-Nov	1950	0	30520	256.8	700	1129	95	0	9450	0	14000	217	19965	213	19614	23450	360850	430	23880
19-Nov	1940	35	32460	291.8	700	1121	96	0	9450	0	14000	193	20158	200	19814	23450	384300	393	23843
20-Nov	1850	0	34310	291.8	700	1154	96	0	8400	0	14000	207	20365	192	20006	22400	406700	399	22799
21-Nov	1760	0	36070	291.8	2355	1074	96	0	6300	5600	7000	292	20657	247	20253	18900	425600	539	19439
22-Nov	1740	50	37810	341.8	200	972	95	0	3150	19600	0	596	21253	548	20801	22750	448350	1144	23894
23-Nov	1940	30	39750	371.8	1200	1013	95	0	5250	16800	0	1439	22692	1314	22115	22050	470400	2753	24803
24-Nov	1780	0	41530	371.8	800	1121	95	0	7350	14000	0	1064	23756	1044	23159	21350	491750	2108	23458
25-Nov	1700	52.8	43230	424.6	600	1044	94	0	2100	19600	0	266	24022	248	23407	21700	513450	514	22214
26-Nov	1570	0	44800	424.6	2000	1025	94	1050	0	19600	0	921	24943	812	24219	20650	534100	1733	22383
27-Nov	1740	37.4	46540	462.0	630	1060	95	3150	0	16800	0	270	25213	259	24478	19950	554050	529	20479
28-Nov	1190	26.4	47730	488.4	1700	1010	88	0	0	14000	0	5030	30243	2808	27286	14000	568050	7838	21838
29-Nov	1590	0	49320	488.4	2000	965	94	0	0	19600	0	1669	31912	0	27286	19600	587650	1669	21269
30-Nov	1860	39.6	51180	528.0	2000	1080	94	2100	1050	16800	0	243	32155	76	27362	19950	607600	319	20269
			51180										32155		27362		607600		

MONTHLY TOTAL KWH PRODUCED **667117**

DIESEL KWH PRODUCED PER GAL OF FUEL **11.87**

% WIND TURBINE KWH PRODUCED TO TOTAL GRID **8.92%**

FUEL SAVINGS BY WIND TURBINE OPERATIONS IN GALLONS (AVOIDED GALLONS USED) **5013**

 Nov 1-3 WT Production lost due to Navy Utilities construction for 3rd Wind Turbine Installation

DECEMBER 1998

SCI Power Plant Production Report																			
	Fuel & Lube Oil Used							Diesel Generators				Wind Turbines				Total Diesel		Tot. WT	Grid Load
	Daily		Total		Daily Pk Demand		Avg	500 KW	500 KW	1.2 MW	750 KW	225 KW WT-1		225 KW WT-2		KWH		KWH	Tot. KWH
Date	Fuel	Lube	Fuel	Lube	Time	Load	PF	DE-1	DE-2	DE-3	DE-4	Daily	CUM	Daily	CUM	Daily	CUM	Daily	Daily
1-Dec	1980	8.8	1980	8.8	1800	1235	95	5250	0	16800	0	774	774	1512	1512	22050	22050	2286	24336
2-Dec	2040	17.6	4020	26.4	2000	1175	96	7350	0	16800	0	197	971	200	1712	24150	46200	397	24547
3-Dec	2910	0	6930	26.4	600	1216	95	6300	0	16800	0	1330	2301	1473	3185	23100	69300	2803	25903
4-Dec	1950	32.2	8880	58.6	700	1009	92	4200	0	16800	0	2498	4799	2417	5602	21000	90300	4915	25915
5-Dec	1460	0	10340	58.6	700	1014	95	7350	0	2800	10500	0	4799	0	5602	20650	110950	0	20650
6-Dec	1750	0	12090	58.6	600	1129	96	7350	0	0	12250	0	4799	0	5602	19600	130550	0	19600
7-Dec	1990	19.4	14080	78.0	1800	1130	97	9450	0	0	15750	4267	9066	5680	11282	25200	155750	9947	35147
8-Dec	2070	20	16150	98.0	500	1317	96	8400	0	11200	3500	876	9942	994	12276	23100	178850	1870	24970
9-Dec	1860	0	18010	98.0	1800	1150	95	6300	0	14000	0	2362	12304	2320	14596	20300	199150	4682	24982
10-Dec	2080	0	20090	98.0	700	1200	96	0	6300	19600	0	173	12477	251	14847	25900	225050	424	26324
11-Dec	1850	25	21940	123.0	700	1200	96	0	4200	16800	0	158	12635	185	15032	21000	246050	343	21343
12-Dec	1720	7	23660	130.0	800	990	95	0	5250	5600	8750	30	12665	286	15318	19600	265650	316	19916
13-Dec	1590	10	25250	140.0	600	900	96	0	5250	5600	8750	1249	13914	1147	16465	19600	285250	2396	21996
14-Dec	1600	4	26850	144.0	1800	1175	95	0	7350	0	10500	2566	16480	3063	19528	17850	303100	5629	23479
15-Dec	1730	37	28580	181.0	1100	1028	96	4200	2100	5600	8750	1260	17740	1675	21203	20650	323750	2935	23585
16-Dec	1780	20	30360	201.0	1200	1056	96	5250	0	16800	0	835	18575	1455	22658	22050	345800	2290	24340
17-Dec	1650	0	32010	201.0	1100	1184	94	1050	0	19600	0	739	19314	673	23331	20650	366450	1412	22062
18-Dec	1490	13.7	33500	214.7	1800	1091	94	6300	0	16800	0	97	19411	90	23421	23100	389550	187	23287
19-Dec	1530	3.9	35030	218.6	1900	1048	95	0	0	11200	0	1527	20938	1483	24904	11200	400750	3010	14210
20-Dec	1320	16.3	36350	234.9	2000	1091	86	0	0	16800	0	3892	24830	3804	28708	16800	417550	7696	24496
21-Dec	1860	27	38210	261.9	1800	1154	96	6300	0	14000	3500	951	25781	1062	29770	23800	441350	2013	25813
22-Dec	2010	13	40220	274.9	700	1200	95	5250	0	16800	0	479	26260	498	30268	22050	463400	977	23027
23-Dec	1830	0	42050	274.9	700	1100	97	4200	0	19600	0	449	26709	516	30784	23800	487200	965	24765
24-Dec	1800	35	43850	309.9	600	1100	96	1050	0	16800	0	194	26903	225	31009	17850	505050	419	18269
25-Dec	1670	15	45520	324.9	600	1016	96	1050	0	22400	0	341	27244	326	31335	23450	528500	667	24117
26-Dec	1610	0	47130	324.9	600	912	96	9450	10500	0	0	117	27361	147	31482	19950	548450	264	20214
27-Dec	1580	0	48710	324.9	600	920	96	9450	10500	0	0	63	27424	85	31567	19950	568400	148	20098
28-Dec	1700	30	50410	354.9	2100	1000	95	2100	0	14000	1750	257	27681	218	31785	17850	586250	475	18325
29-Dec	1790	0	52200	354.9	2000	1005	96	3150	0	19600	0	393	28074	350	32135	22750	609000	743	23493
30-Dec	1740	8.8	53940	363.7	600	1038	95	3150	0	16800	0	352	28426	359	32494	19950	628950	711	20661
31-Dec	1440	10	55380	373.7	600	874	95	1050	0	8400	7000	1090	29516	1028	33522	16450	645400	2118	18568

MONTHLY TOTAL KWH PRODUCED **708438**
DIESEL KWH PRODUCED PER GAL OF FUEL **11.65**
% WIND TURBINE KWH PRODUCED TO TOTAL GRID **8.90%**
FUEL SAVINGS BY WIND TURBINE OPERATIONS IN GALLONS (AVOIDED GALLONS USED) **5409**

12-05-98 Wind Turbines off line ~ 8 hours - Pwr Plant Grid Failure
12-05, 12-06 Computer Display Problem

JANUARY 1999

SCI Power Plant Production Report																			
	Fuel & Lube Oil Used								Diesel Generators				Wind Turbines				Total Diesel		Tot. WT	Grid Load
	Daily		Total		Daily Pk Demand		Avg	500 KW	500 KW	1.2 MW	750 KW	225 KW WT-1		225 KW WT-2		KWH		KWH	Tot. KWH
Date	Fuel	Lube	Fuel	Lube	Time	Load	PF	DE-1	DE-2	DE-3	DE-4	Daily	CUM	Daily	CUM	Daily	CUM	Daily	Daily
1-Jan	1510	27.4	1510	27.4	100	803	95	3150	0	0	14000	606	606	742	742	17150	17150	1348	18498
2-Jan	1580	0	3090	27.4	2000	882	95	5250	0	0	14000	44	650	90	832	19250	36400	134	19384
3-Jan	1540	0	4630	27.4	1900	817	94	5250	0	0	12250	267	917	288	1120	17500	53900	555	18055
4-Jan	1700	24.2	6330	51.6	1800	945	95	7350	0	0	12250	312	1229	400	1520	19600	73500	712	20312
5-Jan	1770	22	8100	73.6	700	1065	94	7350	0	0	12250	397	1626	384	1904	19600	93100	781	20381
6-Jan	1840	10	9940	83.6	600	1081	95	7350	0	0	14000	292	1918	231	2135	21350	114450	523	21873
7-Jan	1780	0	11720	83.6	2000	1110	94	8400	0	0	14000	1493	3411	1402	3537	22400	136850	2895	25295
8-Jan	1630	0	13350	83.6	1000	1025	94	2100	0	16800	0	1255	4666	1224	4761	18900	155750	2479	21379
9-Jan	1630	20	14980	103.6	1800	925	95	0	0	19600	0	91	4757	180	4941	19600	175350	271	19871
10-Jan	1630	8	16610	111.6	1800	963	95	1050	0	16800	0	0	4757	34	4975	17850	193200	34	17884
11-Jan	1800	35	18410	146.6	1900	1137	94	3150	0	19600	0	566	5323	530	5505	22750	215950	1096	23846
12-Jan	2010	10	20420	156.6	800	1190	95	5250	0	19600	0	432	5755	598	6103	24850	240800	1030	25880
13-Jan	2090	22	22510	178.6	700	1238	95	7350	0	16800	0	3	5758	100	6203	24150	264950	103	24253
14-Jan	1970	22	24480	200.6	600	1204	95	8400	0	14000	0	194	5952	691	6894	22400	287350	885	23285
15-Jan	1690	22	26170	222.6	700	1023	0	2100	0	16800	0	288	6240	365	7259	18900	306250	653	19553
16-Jan	1430	17.6	27600	240.2	2300	902	95	0	0	16800	0	2271	8511	2181	9440	16800	323050	4452	21252
17-Jan	1410	20	29010	260.2	1900	997	95	2100	0	19600	0	517	9028	473	9913	21700	344750	990	22690
18-Jan	1680	0	30690	260.2	900	928	95	0	0	19600	0	310	9338	307	10220	19600	364350	617	20217
19-Jan	1880	40	32570	300.2	1900	1209	95	5250	0	16800	0	687	10025	684	10904	22050	386400	1371	23421
20-Jan	1650	0	34220	300.2	1800	1250	90	4200	0	14000	0	3643	13668	3476	14380	18200	404600	7119	25319
21-Jan	1460	0	35680	300.2	700	1210	86	1050	0	16800	0	4306	17974	4102	18482	17850	422450	8408	26258
22-Jan	1890	35.5	37570	335.7	600	1160	91	4200	0	14000	1750	326	18300	344	18826	19950	442400	670	20620
23-Jan	1880	15	39450	350.7	700	1075	92	8400	0	0	12250	191	18491	180	19006	20650	463050	371	21021
24-Jan	1750	19.9	41200	370.6	1900	1110	90	8400	0	0	14000	1608	20099	1590	20596	22400	485450	3198	25598
25-Jan	1870	19.8	43070	390.4	1900	1250	91	8400	0	0	12250	1691	21790	1610	22206	20650	506100	3301	23951
26-Jan	1780	0	44850	390.4	1900	1395	90	9450	0	0	14000	3474	25264	3367	25573	23450	529550	6841	30291
27-Jan	2080	0	46930	390.4	800	1381	95	7350	0	14000	5250	1239	26503	1360	26933	26600	556150	2599	29199
28-Jan	2160	13.2	49090	403.6	600	1330	95	8400	0	19600	0	333	26836	330	27263	28000	584150	663	28663
29-Jan	2060	35	51150	438.6	700	1280	95	7350	0	16800	0	230	27066	237	27500	24150	608300	467	24617
30-Jan	1880	0	53030	438.6	600	1104	95	5250	0	16800	0	53	27119	256	27756	22050	630350	309	22359
31-Jan	1650	15	54680	453.6	2300	1031	94	4200	0	14000	0	1863	28982	2577	30333	4200	634550	4440	22640

MONTHLY TOTAL KWH PRODUCED **693865**

KWH PRODUCED PER GAL OF FUEL **11.60**

% WIND TURBINE KWH PRODUCED TO TOTAL GRID **8.55%**

FUEL SAVINGS BY WIND TURBINE OPERATIONS IN GALLONS (AVOIDED GALLONS USED) **5111.**

FEBRUARY 1999

SCI Power Plant Production Report																			
	Fuel & Lube Oil Used							Diesel Generators				Wind Turbines				Total Diesel		Tot. WT	Grid Load
	Daily		Total		Daily Pk Demand		Avg	500 KW	500 KW	1.2 MW	750 KW	225 KW WT-1		225 KW WT-2		KWH		KWH	Tot. KWH
Date	Fuel	Lube	Fuel	Lube	Time	Load	PF	DE-1	DE-2	DE-3	DE-4	Daily	CUM	Daily	CUM	Daily	CUM	Daily	Daily
1-Feb	2000	37	2000	37.0	2000	1109	95	7350	0	16800	0	360	360	508	508	24150	24150	868	25018
2-Feb	2090	12.3	4090	49.3	700	1171	96	4200	0	16800	1750	83	443	403	911	22750	46900	486	23236
3-Feb	2150	18.5	6240	67.8	600	1260	92	9450	0	16800	0	0	443	140	1051	26250	73150	140	26390
4-Feb	2140	20	8380	87.8	2100	1280	93	7350	0	16800	0	845	1288	1187	2238	24150	97300	2032	26182
5-Feb	1960	37.2	10340	125.0	700	1220	94	4200	2100	16800	0	1127	2415	1083	3321	23100	120400	2210	25310
6-Feb	1790	0	12130	125.0	1800	1105	94	0	5250	8400	7000	1344	3759	1274	4595	20650	141050	2618	23268
7-Feb	1870	17.6	14000	142.6	1900	1115	94	0	9450	0	14000	781	4540	763	5358	23450	164500	1544	24994
8-Feb	1950	20	15950	162.6	1800	1242	96	0	9450	0	14000	460	5000	433	5791	23450	187950	893	24343
9-Feb	1830	0	17780	162.6	1600	1300	96	0	8400	2800	10500	2092	7092	1962	7753	21700	209650	4054	25754
10-Feb	1840	17.6	19620	180.2	700	1360	93	0	6300	11200	3500	2602	9694	3548	11301	21000	230650	6150	27150
11-Feb	1750	14.5	21370	194.7	600	1255	92	0	6300	14000	0	2923	12617	2899	14200	20300	250950	5822	26122
12-Feb	1920	33	23290	227.7	600	1324	94	0	6300	16800	0	515	13132	546	14746	23100	274050	1061	24161
13-Feb	1820	0	25110	227.7	700	1080	94	0	4200	16800	0	852	13984	762	15508	21000	295050	1614	22614
14-Feb	1540	25	26650	252.7	500	1046	90	0	4200	14000	0	3321	17305	3169	18677	18200	313250	6490	24690
15-Feb	1660	15	28310	267.7	600	1118	94	0	3150	16800	0	1903	19208	1855	20532	19950	333200	3758	23708
16-Feb	1850	0	30160	267.7	700	1153	93	0	6300	14000	0	2235	21443	2199	22731	20300	353500	4434	24734
17-Feb	1880	35	32040	302.7	600	1280	94	0	6300	14000	0	2561	24004	2548	25279	20300	373800	5109	25409
18-Feb	1930	0	33970	302.7	700	1118	94	0	7350	16800	0	1781	25785	1669	26948	24150	397950	3450	27600
19-Feb	1930	181	35900	483.7	700	1201	95	5250	0	16800	0	568	26353	530	27478	22050	420000	1098	23148
20-Feb	1840	10	37740	493.7	600	1139	94	7350	0	5600	8750	1030	27383	946	28424	21700	441700	1976	23676
21-Feb	1510	50	39250	543.7	600	1160	95	5250	0	0	12250	3505	30888	4069	32493	17500	459200	7574	25074
22-Feb	1820	0	41070	543.7	600	1172	95	8400	0	0	12250	1078	31966	1785	34278	20650	479850	2863	23513
23-Feb	1940	0	43010	543.7	1800	1140	94	9450	0	0	14000	240	32206	210	34488	23450	503300	450	23900
24-Feb	1960	10	44970	553.7	700	1279	94	6300	0	14000	1750	873	33079	978	35466	22050	525350	1851	23901
25-Feb	1850	28	46820	581.7	1900	1300	93	6300	0	16800	0	2214	35293	2260	37726	23100	548450	4474	27574
26-Feb	1940	0	48760	581.7	700	1144	94	6300	0	16800	0	761	36054	725	38451	23100	571550	1486	24586
27-Feb	1880	46	50640	627.7	700	1060	95	9450	0	0	12250	115	36169	114	38565	21700	593250	229	21929
28-Feb	1860	0	52500	627.7	1800	1049	94	2100	7350	0	14000	199	36368	720	39285	23450	616700	919	24369

MONTHLY TOTAL KWH PRODUCED **692353**

DIESEL KWH PRODUCED PER GAL OF FUEL **11.75**

% WIND TURBINE KWH PRODUCED TO TOTAL GRID **10.93%**

FUEL SAVINGS BY WIND TURBINE OPERATIONS IN GALLONS (AVOIDED GALLONS USED) **6440**

MARCH 1999

SCI Power Plant Production Report																			
	Fuel & Lube Oil Used								Diesel Generators			Wind Turbines				Total Diesel		Tot. WT	Grid Load
	Daily		Total		Daily Pk Demand		Avg	500 KW	500 KW	1.2 MW	750 KW	225 KW WT-1		225 KW WT-2		KWH		KWH	Tot. KWH
Date	Fuel	Lube	Fuel	Lube	Time	Load	PF	DE-1	DE-2	DE-3	DE-4	Daily	CUM	Daily	CUM	Daily	CUM	Daily	Daily
1-Mar	1780	0	1780	0.0	2300	1139	93	0	7350	0	12250	995	995	1204	1204	19600	19600	2199	21799
2-Mar	1830	0	3610	0.0	2000	1181	92	1050	7350	0	12250	1892	2887	1770	2974	20650	40250	3662	24312
3-Mar	1710	0	5320	0.0	600	1254	94	0	7350	2800	10500	3385	6272	3355	6329	20650	60900	6740	27390
4-Mar	1760	0	7080	0.0	700	1305	94	4200	0	16800	0	2633	8905	2536	8865	21000	81900	5169	26169
5-Mar	2090	17	9170	17.0	700	1211	95	7350	0	16800	0	2	8907	56	8921	24150	106050	58	24208
6-Mar	2110	0	11280	17.0	2000	1203	94	9450	0	2800	12250	211	9118	240	9161	24500	130550	451	24951
7-Mar	1860	0	13140	17.0	1900	1265	94	9450	0	2800	12250	1014	10132	2126	11287	24500	155050	3140	27640
8-Mar	1940	20	15080	37.0	2100	1215	95	8400	0	11200	3500	1312	11444	1313	12600	23100	178150	2625	25725
9-Mar	2020	20	17100	57.0	1900	1352	94	8400	0	19600	0	1174	12618	1352	13952	28000	206150	2526	30526
10-Mar	1950	0	19050	57.0	1900	1382	91	8400	0	16800	0	2888	15506	2896	16848	25200	231350	5784	30984
11-Mar	2030	55	21080	112.0	800	1395	91	7350	0	16800	0	1595	17101	1883	18731	24150	255500	3478	27628
12-Mar	1890	0	22970	112.0	500	1211	93	4200	0	19600	0	367	17468	362	19093	23800	279300	729	24529
13-Mar	1830	0	24800	112.0	2000	1070	94	3150	0	16800	0	375	17843	358	19451	19950	299250	733	20683
14-Mar	1920	22	26720	134.0	2000	1069	94	7350	0	16800	0	410	18253	421	19872	24150	323400	831	24981
15-Mar	1840	22	28560	156.0	1100	1296	94	7350	0	14000	0	1827	20080	1884	21756	21350	344750	3711	25061
16-Mar	1970	0	30530	156.0	600	1146	96	9450	0	14000	0	424	20504	622	22378	23450	368200	1046	24496
17-Mar	2290	40	32820	196.0	1900	1228	96	9450	0	16800	0	181	20685	346	22724	26250	394450	527	26777
18-Mar	2180	18	35000	214.0	2200	1205	96	7350	3150	16800	0	100	20785	123	22847	27300	421750	223	27523
19-Mar	1980	13	36980	227.0	700	1151	96	0	8400	8400	5250	456	21241	656	23503	22050	443800	1112	23162
20-Mar	1890	0	38870	227.0	2100	1043	96	0	8400	0	14000	338	21579	398	23901	22400	466200	736	23136
21-Mar	1840	35	40710	262.0	700	1027	96	2100	7350	0	12250	1007	22586	1115	25016	21700	487900	2122	23822
22-Mar	2620	9	43330	271.0	600	1090	96	9450	0	0	10500	2189	24775	2354	27370	19950	507850	4543	24493
23-Mar	1920	22	45250	293.0	2000	1128	96	9450	0	5600	10500	1856	26631	1796	29166	25550	533400	3652	29202
24-Mar	2100	0	47350	293.0	600	1244	95	8400	0	16800	0	1234	27865	1302	30468	25200	558600	2536	27736
25-Mar	2180	13	49530	306.0	1200	1258	95	9450	0	16800	0	641	28506	1139	31607	26250	584850	1780	28030
26-Mar	1880	38	51410	344.0	2300	1114	94	6300	0	16800	0	1566	30072	1840	33447	23100	607950	3406	26506
27-Mar	1960	0	53370	344.0	600	1005	96	7350	0	14000	0	170	30242	163	33610	21350	629300	333	21683
28-Mar	1950	0	55320	344.0	600	1060	95	1050	8400	2800	8750	752	30994	675	34285	21000	650300	1427	22427
29-Mar	1930	0	57250	344.0	2100	1125	94	0	10500	0	14000	115	31109	138	34423	24500	674800	253	24753
30-Mar	1680	16	58930	360.0	800	996	93	0	8400	0	10500	3607	34716	3500	37923	18900	693700	7107	26007
31-Mar	1610	20	60540	380.0	900	1325	88	0	7350	0	10500	4989	39705	4942	42865	10500	704200	9931	27781

MONTHLY TOTAL KWH PRODUCED 786770

DIESEL KWH PRODUCED PER GAL OF FUEL 11.63

% WIND TURBINE KWH PRODUCED TO TOTAL GRID 10.49%

FUEL SAVINGS BY WIND TURBINE OPERATIONS IN GALLONS (AVOIDED GALLONS USED) 7099

APRIL 1999

SCI Power Plant Production Report																			
	Fuel & Lube Oil Used								Diesel Generators				Wind Turbines				Total Diesel		Tot. WT	Grid Load
	Daily		Total		Daily Pk Demand		Avg	500 KW	500 KW	1.2 MW	750 KW	225 KW WT-1		225 KW WT-2		KWH		KWH	Tot. KWH
Date	Fuel	Lube	Fuel	Lube	Time	Load	PF	DE-1	DE-2	DE-3	DE-4	Daily	CUM	Daily	CUM	Daily	CUM	Daily	Daily
1-Apr	1890	24	1890	24.0	700	1340	90	0	5250	16800	0	2797	2797	3006	3006	22050	22050	5803	27853
2-Apr	1760	191	3650	215.0	500	1200	90	0	6300	8400	7000	2144	4941	3084	6090	21700	43750	5228	26928
3-Apr	1590	0	5240	215.0	2400	1225	90	0	5250	0	14000	3724	8665	3577	9667	19250	63000	7301	26551
4-Apr	1590	13.2	6830	228.2	100	1165	90	0	6300	0	12250	2416	11081	2432	12099	18550	81550	4848	23398
5-Apr	1890	0	8720	228.2	2200	1155	90	0	9450	0	14000	1178	12259	1146	13245	23450	105000	2324	25774
6-Apr	2070	0	10790	228.2	900	1275	90	0	9450	0	14000	423	12682	629	13874	23450	128450	1052	24502
7-Apr	1900	41.8	12690	270.0	2300	1222	94	0	9450	0	14000	2438	15120	2582	16456	23450	151900	5020	28470
8-Apr	1910	0	14600	270.0	600	1224	92	0	8400	0	14000	1880	17000	1802	18258	22400	174300	3682	26082
9-Apr	1610	13.2	16210	283.2	800	1193	92	0	7350	0	10500	4052	21052	4623	22881	17850	192150	8675	26525
10-Apr	1960	0	18170	283.2	700	1232	93	0	9450	0	15750	870	21922	853	23734	25200	217350	1723	26923
11-Apr	1920	13.2	20090	296.4	1200	1149	94	0	8400	0	14000	1513	23435	1398	25132	22400	239750	2911	25311
12-Apr	2010	13.2	22100	309.6	600	1205	95	5250	4200	11200	5250	1243	24678	1164	26296	25900	265650	2407	28307
13-Apr	2140	39.6	24240	349.2	1000	1230	95	8400	0	16800	0	506	25184	464	26760	25200	290850	970	26170
14-Apr	2200	0	26440	349.2	1100	1337	94	9450	0	16800	0	315	25499	284	27044	26250	317100	599	26849
15-Apr	2100	30	28540	379.2	800	1230	95	9450	0	16800	0	106	25605	105	27149	26250	343350	211	26461
16-Apr	1470	32	30010	411.2	600	1135	95	7350	0	8400	5250	208	25813	370	27519	21000	364350	578	21578
17-Apr	1900	0	31910	411.2	600	948	95	0	5250	0	12250	394	26207	365	27884	17500	381850	759	18259
18-Apr	1540	35	33450	446.2	2000	870	94	0	5250	0	12250	645	26852	603	28487	17500	399350	1248	18748
19-Apr	1630	0	35080	446.2	1800	1010	94	0	6300	0	14000	938	27790	850	29337	20300	419650	1788	22088
20-Apr	1380	0	36460	446.2	2100	956	94	0	3150	0	12250	3254	31044	3049	32386	15400	435050	6303	21703
21-Apr	1300	0	37760	446.2	2100	1125	86	0	4200	0	10500	3323	34367	3248	35634	14700	449750	6571	21271
22-Apr	1600	9.3	39360	455.5	800	1089	90	0	4200	0	10500	2053	36420	1979	37613	14700	464450	4032	18732
23-Apr	1740	29.4	41100	484.9	500	1032	94	0	8400	2800	14000	379	36799	394	38007	25200	489650	773	25973
24-Apr	1600	0	42700	484.9	2000	905	94	0	0	16800	0	144	36943	144	38151	16800	506450	288	17088
25-Apr	1470	0	44170	484.9	2000	894	93	0	0	19600	0	1071	38014	1026	39177	19600	526050	2097	21697
26-Apr	1670	27.3	45840	512.2	2100	964	94	0	2100	16800	0	1408	39422	1383	40560	18900	544950	2791	21691
27-Apr	1600	0	47440	512.2	2000	1030	89	0	3150	16800	0	2313	41735	2270	42830	19950	564900	4583	24533
28-Apr	1430	15	48870	527.2	1400	1215	94	1050	0	14000	0	4605	46340	4620	47450	15050	579950	9225	24275
29-Apr	1500	15	50370	542.2	700	1204	95	1050	0	16800	0	4033	50373	4004	51454	17850	597800	8037	25887
30-Apr	1780	25	52150	567.2	1400	1130	94	3150	0	16800	0	699	51072	668	52122	19950	617750	1367	21317
	0	0	52150	567.2	0000	0	0	0	0	0	0	0	51072	0	52122	0	617750	0	0

MONTHLY TOTAL KWH PRODUCED 720944

DIESEL KWH PRODUCED PER GAL OF FUEL 11.85

% WIND TURBINE KWH PRODUCED TO TOTAL GRID 14.31%

FUEL SAVINGS BY WIND TURBINE OPERATIONS IN GALLONS (AVOIDED GALLONS USED) 8712

May 1999

	Fuel & Lube Oil Used								Diesel Generators				Wind Turbines				Total Diesel		Tot. WT	Grid Load
	Daily		Total		Daily Pk Demand		Avg	500 KW	500 KW	1.2 MW	750 KW	225 KW WT-1		225 KW WT-2		KWH		KWH	Tot. KWH
Date	Fuel	Lube	Fuel	Lube	Time	Load	PF	DE-1	DE-2	DE-3	DE-4	Daily	CUM	Daily	CUM	Daily	CUM	Daily	Daily
1-May	1730	30	1730	30.0	2100	1027	95	8400	0	0	10500	712	712	667	667	18900	18900	1379	20279
2-May	1520	0	3250	30.0	2000	1011	94	0	4200	0	12250	2413	3125	2366	3033	16450	35350	4779	21229
3-May	1350	10	4600	40.0	2000	1118	94	0	2100	0	14000	4331	7456	4309	7342	16100	51450	8640	24740
4-May	1610	5	6210	45.0	600	1125	95	0	5250	0	14000	2930	10386	2834	10176	19250	70700	5764	25014
5-May	2040	31.3	8250	76.3	800	1185	95	0	9450	0	15750	90	10476	97	10273	25200	95900	187	25387
6-May	1900	0	10150	76.3	1100	1051	95	0	7350	0	14000	453	10929	396	10669	21350	117250	849	22199
7-May	1630	14	11780	90.3	800	948	93	0	4200	8400	7000	1133	12062	1060	11729	19600	136850	2193	21793
8-May	1540	14	13320	104.3	1800	894	94	0	0	16800	0	679	12741	642	12371	16800	153650	1321	18121
9-May	1540	12.7	14860	117.0	1900	942	95	0	0	19600	0	511	13252	474	12845	19600	173250	985	20585
10-May	1660	18.9	16520	135.9	2000	952	94	0	0	19600	0	271	13523	264	13109	19600	192850	535	20135
11-May	1790	42	18310	177.9	2200	1002	95	7350	0	8400	8750	87	13610	76	13185	24500	217350	163	24663
12-May	1900	12	20210	189.9	1300	1021	95	7350	0	14000	0	256	13866	243	13428	21350	238700	499	21849
13-May	1900	0	22110	189.9	2300	987	95	8400	0	1400	0	102	13968	102	13530	9800	248500	204	10004
14-May	1600	31	23710	220.9	600	1035	95	4200	0	11200	0	1693	15661	1650	15180	15400	263900	3343	18743
15-May	1390	15	25100	235.9	700	865	95	0	3150	0	14000	2263	17924	2270	17450	17150	281050	4533	21683
16-May	1630	0	26730	235.9	900	890	95	0	3150	8400	8750	294	18218	273	17723	20300	301350	567	20867
17-May	1710	20	28440	255.9	700	948	95	1050	0	19600	0	70	18288	66	17789	20650	322000	136	20786
18-May	1710	18	30150	273.9	500	953	95	2100	0	16800	0	908	19196	849	18638	18900	340900	1757	20657
19-May	1480	20	31630	293.9	1000	980	94	1050	0	16800	0	2553	21749	2445	21083	17850	358750	4998	22848
20-May	1660	1.3	33290	295.2	600	920	94	0	5250	5600	10500	2123	23872	2071	23154	21350	380100	4194	25544
21-May	1930	10	35220	305.2	600	1101	95	0	9450	0	14000	64	23936	65	23219	23450	403550	129	23579
22-May	1860	0	37080	305.2	2200	1055	95	0	7350	0	14000	76	24012	71	23290	21350	424900	147	21497
23-May	1830	28	38910	333.2	600	1031	95	0	8400	0	14000	234	24246	212	23502	22400	447300	446	22846
24-May	1680	10	40590	343.2	2200	1005	95	0	7250	0	12250	1797	26043	1709	25211	19500	466800	3506	23006
25-May	1800	0	42390	343.2	600	1022	95	0	8400	0	12250	1163	27206	1085	26296	20650	487450	2248	22898
26-May	1920	18	44310	361.2	1200	1150	94	0	8400	0	14000	809	28015	766	27062	22400	509850	1575	23975
27-May	1800	26	46110	387.2	1900	1070	94	0	7350	0	14000	1024	29039	937	27999	21350	531200	1961	23311
28-May	1610	0	47720	387.2	700	1000	93	0	5250	8400	7000	1490	30529	1427	29426	20650	551850	2917	23567
29-May	1550	2	49270	389.2	2300	1035	93	0	0	16800	0	1590	32119	1541	30967	16800	568650	3131	19931
30-May	1560	28	50830	417.2	2100	970	93	0	0	19600	0	1268	33387	1197	32164	19600	588250	2465	22065
31-May	1540	0	52370	417.2	2200	905	93	0	0	16800	0	1032	34419	1016	33180	16800	605050	2048	18848

MONTHLY TOTAL KWH PRODUCED	**672649**
DIESEL KWH PRODUCED PER GAL OF FUEL	**11.55**
% WIND TURBINE KWH PRODUCED TO TOTAL GRID	**10.05%**
FUEL SAVINGS BY WIND TURBINE OPERATIONS IN GALLONS (AVOIDED GALLONS USED)	**5851**

APPENDIX C:
Independent Paper on Wind-Diesel Hybrid Energy System Design and Operation [6]

This appendix was included to display some of the earlier design and operational strategy developed by NREL and NREL sub-contractors for the remote wind-diesel system.

The Evaluation of the Wind Resource at San Nicolas Island

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Introduction

One use of renewable energy in the near term is the addition of wind turbines on isolated, (non-intertied, non-grid-connected), electrical systems such as on small to moderately populated islands or in very remote, sparsely populated areas. Such systems are usually powered by diesel engines. While fairly large wind systems have been installed in diesel powered grids on several of the off-shore islands in Great Britain, and also on some islands off the coast of Norway, none in a class of systems comprising a megawatt or more has ever been installed in the United States, it's possessions or protectorates.

This report provides an assessment of the wind energy potential on one island owned by the U.S. Navy off the southwest coast of California. The wind energy atlases produced by the Pacific Northwest Laboratory and it's subcontractors over a decade ago, assessed the Channel Islands as having a class two wind resource - a rather low value. A more recent look and a number of qualitative indications gave rise to a program to collect some new wind data in an area appropriate for the installation of wind turbines on the island. This assessment makes use of that data. The assessment has been accomplished in a manner that went beyond the normal resource assessment in that it was done with the current diesel system in mind and in a manner <u>not</u> necessarily intended to maximize the wind energy capture but to integrate as much wind energy as possible without causing any significant disruption to the existing system other than to reduce it's costs and the effluent of pollutants. The system under study here is the U.S. Navy's San Nicolas Island, California. The secondary purpose of this report is to document the efficacy of a simple spreadsheet model to perform such resource assessments.

The report is comprised of nine sections. Immediately following this Introduction is a section on the Background and history of this assessment and model development task. This is immediately followed by a concise statement of the purpose of the project and the model. The fourth section elucidates the assumptions that had to be made in developing the model. While the terminology 'assumption' might elicit the thought that the model is somewhat subjective, the section includes justification for each and every assumption and the potential effect of the assumption.

A separate section on the existing power system on the island follows. Though it might well have been placed further forward in the Background section, it was placed where it is so that the technical background material included was in closer proximity to the remainder of the technical development of the system. The model, as will be explained later, was developed based on hourly average data. The description of the data and it's sources comprises the following section. Thereafter the reader will find the details of the development of the spreadsheet model which lacks a name since it is based on commercially available software.

When designing large machinery or complex systems, the ultimate driver for the project is typically, economics. The next section outlines the economics of the system. Obtaining many of the inputs to the economics was tenuous leading to the uneasy feeling that the numbers were something akin to a "guess". Some of the costs for the turbines is admittedly a guess based on some experience. In all cases, it is believed that the values used are at least conservative. The final two sections show the results of the modeling effort and what conclusions can be drawn from the results. Recommendations have not been included as that seemed inappropriate and self-serving at best.

Background

Since 1994, the U.S. Navy, with the help of the National Renewable Energy Laboratory, (NREL) has been taking wind and related data on several of the Channel Islands off the coast of Southern California. The purpose of this effort was to evaluate the technical and economic potential of integrating wind energy into the diesel powered grid at a non-grid connected military installation. Further, wind energy needed to be evaluated as a means to both reduce the consumption of diesel fuel and abate the discharge of pollutants into the atmosphere. One of these island facilities among the Channel Island group, San Clemente Island, is moving ahead with the acquisition of wind turbines to integrate into the island power system. The island of interest in this report, however, is San Nicolas Island. While there is no immediate plan to incorporate wind energy on the island, there is a sufficient interest in wind energy to warrant performing this assessment and system operations modeling effort.

Several groups have moved in the direction of modeling wind/diesel systems in an effort to demonstrate the utility of adding wind to a diesel system. The number of diesel powered, islanded grids on the face of the earth probably approaches ten thousand. Not all of these have viable wind resources to draw on but many may. The great majority of these are probably systems with a maximum peak demand of less than 100KW - relatively small village communities. Some preliminary analyses of these smaller system leads to the conclusion that the most desirable system and end effect can only be attained if the diesel(s) can be totally shut off. For small systems that can afford some small amount of battery or other storage, this is probably true. In a system comprising a 1000kW or more, the addition of multi-MWh capacity batteries is 1) too expensive and 2) extremely maintenance intensive and, 3) an environmental hazard. Therefore, battery storage was not included in the scenario.

One high resolution, wind/diesel model, HYBRID2, is a simulation model with many diverse attributes. It has the capability to simulate minute by minute operations of a wind/hybrid/diesel system that can include storage and any or all of a number of prominent renewable technologies. It was developed by the University of Massachusetts in conjunction with NREL and sponsored by the U. S. Department of Energy. HYBRID2 may well be the epitome of hybrid energy system models with multiple resource modeling capability. However, for cases where only hourly wind and load data are available, a sophisticated model such as this are not justified. Models of this nature may be an expert tool to help define and describe an optimum operating strategy and even to specify optimal component sizes but are not practical tools for looking at low resolution, resource assessment type data.

Purpose

The purpose of this report, as stated previously, is two-fold. The first and most important is to provide an assessment of the wind resource at San Nicolas and the potential interactions of wind turbines with the diesel system. The second is to document the development and operation of a simple model of a wind/diesel system based on a MicroSoft Excel® Spread Sheet. It should be pointed out that developing a "model" per se, was not in the definition of the task. The resulting model, while being fairly versatile, is not a model in the true sense of the term but could be converted easily enough.

The data used in this analysis was also run in the HYBRID2 model and results were obtained by another investigator. At the time this work is being done, the HYBRID2 model had not been fully validated and for the simulation run, the model was apparently allowed to specify the operating strategy of the diesel system including picking the optimum engine(s) to have on line as well as total engine shutdown. While this is an ideal operating situation, it is unrealistic in the example. A simple spread sheet model has the advantage of being as flexible and/or as complex as one is willing to program it.

Assumptions in the Spreadsheet Model

While the author, a long time advocate of wind energy, would hope that the results of any model would work to the utmost advantage of wind energy, the task of assessing the value of the resource with the spreadsheet model has been carried out very conservatively. The data handling techniques and the modeling development have all been accomplished with a conservative bent. The idea was to "let the chips fall where they may". None of the data was modified in any way other than to move a portion of one set as explained below. No exponent was applied to the wind speed data nor was their any atmospheric density correction. Since the altitude of the site is only about 700 ft., a density correction would only amount to a factor of about .05

In the modeling and assessment effort, the load and wind data were used as provided. No finer scale data was available to develop power spectral density functions of within-hour load or wind speed variances. As noted above no shear exponent was applied which should have evidenced an increase in wind speeds generally whereas the small density correction would have worked the other direction essentially nullifying the shear induced increase. Since the wind input data is averaged over hourly periods, the subsequent convolution of the wind turbine generator power curve with the hourly average wind data should produce a reasonably conservative estimate of the energy produced. This is due to the fact that while the averaging process is linear, the power available in the wind follows the equation:

$$P = \frac{1}{2} \rho A V^3$$

where P = available power in the wind, ρ = atmospheric density, and V = the wind speed, and the curve fit to the wind includes a cubic function thereby producing the under-estimates.

Wind resource data is usually analyzed and condensed into a convenient characteristic distribution such as the two parameter Weibull or the simpler, single parameter Rayleigh distribution in which the K (shape) parameter is set constant at 2. The concept of fitting a Weibull or Rayleigh distribution function to annual hourly averaged wind data and convoluting the fit with the power curve of a specific wind turbine to ascribe an estimated annual energy capture was successfully challenged over a decade ago. With the large, multi-megawatt wind turbines such as the MOD-1 and MOD-2 that were under development at the time, there was concern that the time derivatives in the operating strategy weren't being adequately represented. Such methods of estimating annual energy capture did prove to be significantly in error (over-estimates).

As mentioned earlier, the HYBRID2 model was apparently allowed to dictate the operating strategy of the diesel power plant. The spread sheet model also applied certain constraints. The only constraint on the diesel system was to set the minimum allowable load remaining on the system for the diesel plant to pick up. For the current presentation, the lower limit was set at 200KW minimum load. (A second iteration with the minimum set at 100KW was also run). This was based on the fact that wind turbines incorporating induction generators require some system load to work into or the system voltage and frequency become unstable. Obviously, induction machines also require field magnetization current from the line By setting this constraint it is felt one can maintain system stability (frequency and voltage) and reliability. The number, 200KW, could as well have been 100 or 500.

The San Nicolas power system

The array of diesel engines that are available to serve load on San Nicolas Island include two Caterpillar diesels with a capacity of 750KW each and three EMD diesels with capacities of 500KW(2) and 1000KW(1). In a typical large utility operation, pairs of engines would be operated such that either one could pick up the entire expected load should the other engine fail or trip off line for some untoward reason. It is not known if the power plant on San Nicolas is equipped with Woodward Governors and Load Share devices like San Clemente's powerhouse is, but it is presumed they are. The incorporation of this apparatus makes the operation of the diesel plant fairly simple and manages whatever engines are on line.

Frequently, people apply a "rule of thumb" that a diesel generator should never be run below the 40% load level. The author's experience with large (megawatt and larger) diesels suggested that this was quite possibly hyperbole rather than fact. The Electro-Motive Division (EMD) of Detroit Diesel in LaGrange, Illinois, was contacted to determine the minimum operating conditions for EMD engines. The engineering department indicated that as long as the engines were loaded to a higher level - say 60-80% of rated - for a while before being shut off, there was no problem running them at 10% load, for many hours. They pointed out that railroad locomotives are commonly left running at idle for entire weekends. It has also been pointed out that maintaining engine temperature is mandatory and in these large, sub- and multi-megawatt stationary engines, circulation of coolant and the maintenance of temperature is quite easy and usually accomplished with electrically operated, proportional controllers rather than mechanical thermostats.

A significant factor in the philosophy of the spread sheet model is related to human engineering. The Navy's interest is also in maintaining system reliability - that is, a minimum of potential system outages. The typical utility system operating strategy would operate with two engines on line and the load, assuming the presence of LoadShare devices, would be proportionally split. For instance, with the 750KW and a 500KW diesel running, the 750KW engine would be called upon to provide about 60% of the total load and the 500KW engine would provide the remaining 40%. The combination of diesels that the operators put on line at San Clemente is a function of the anticipated loads. For example, in the middle of the night with minimum load and no expected operational or abnormal load increases, the load is usually only about 450kW. Under these circumstances the operators would likely have two 500kW generators on line. Each would be running at about 50% load on average *with no wind energy installed*. In reality, on both islands, the operators are familiar and comfortable with their systems that they frequently operate with only one engine running at any time.

If significant wind energy was added to the system there is a finite possibility that more wind energy would be available than needed. With the addition of as many as four 225kW rated wind turbines there is a very good possibility that the island might experience sufficient wind for the wind turbines to be generating their rated power of 225kW. Obviously, with two or more turbines running and the system load at it's minimum, (~450kW) the system would be unstable. By constraining the wind turbines to only make up the difference between a minimum set point, say 200kW, and the total load, we might be left with only one wind turbine operating (depending on load) but the operating diesel(s) running at a 450kW or a little over 100kW each if the pair were running (about 20% load), well within the safe operating envelope. Obviously, with this sort of operating strategy the system is not minimizing the amount of diesel fuel used but by doing so we have maintained system stability and reliability and the operators are confident that their system will handle the load without interruption. As will be seen later, even with this less than maximum incorporation and utilization of wind, the economics of the entire system appear to be good.

The Data

The San Nicolas Island wind data is hourly average data. The data were collected on a tower located in reasonable proximity to the area available for wind turbine installation. The data were collected at the 30.5 meter (100') level, a reasonable approximation to the likely hub height for modern wind turbines. The units of measure are meters/second. They are averaged from 10-minute averages. No other sample statistics such as the hourly standard deviation, skewness or kurtosis were available to the author.

The hourly system load data in kilowatts, was transcribed from the operators hand written records to a spread sheet and represent, at least crudely, the operators best guess or "eyeball average" load for the hour. While this is not a terribly satisfying source for such data, looking at daily, weekly and monthly time series plots of the data does not reveal any obvious anomalies in the load and is acceptable for the purposes of this report.

The two data sets were not for synonymous periods of time but had 10 months overlap on an annual basis. The wind data collection began on August 1, 1994 and ran for a year while the load data were for the year October 1, 1989 through September, 1990. Since the model is meant to be "representative" of any year, it was decided to shift the load data to mate August and September 1990 loads to the August and September 1994 wind data. It has been pointed out that some form of newer load data is available that indicates an annual increase in load and the suggestion was made that an across-the-board increase be applied to the data but the author has chosen not to do that for a number of reasons.

Table 1. The load and wind data overlap. The Aug/Sept Load data were cut and pasted on to the front of the load file.

Load	1989			Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
Wind	1994	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul		

To represent the wind turbine, the power curve for a current model, 225KW rated wind turbine was used. The manufacturers literature included a 23 point tabulation of the wind speed vs. power output. This data was truncated at the 18 meter/second inflection point in the curve and a polynomial fit was developed. Second, third, fourth and fifth order fits were then calculated with the results shown in table 2

Table 2 Results of fitting the Micon power curve data to a polynomial curve of several orders.

Order of Fit	Residual Variance	Coef. Of Determination (R^2)
2	232.28	.9743
3	49.28	.9949
4	9.56	.9991
5	8.68	.9993

The fourth order was chosen since the residual variance was not reduced significantly by going to the fifth order and coefficient of determination (goodness of fit) was insignificantly better at the fifth order than for the fourth order fit. The power curve when fit with the fourth order polynomial along with the original power curve provided by the manufacturer is shown in Figure 1 below.

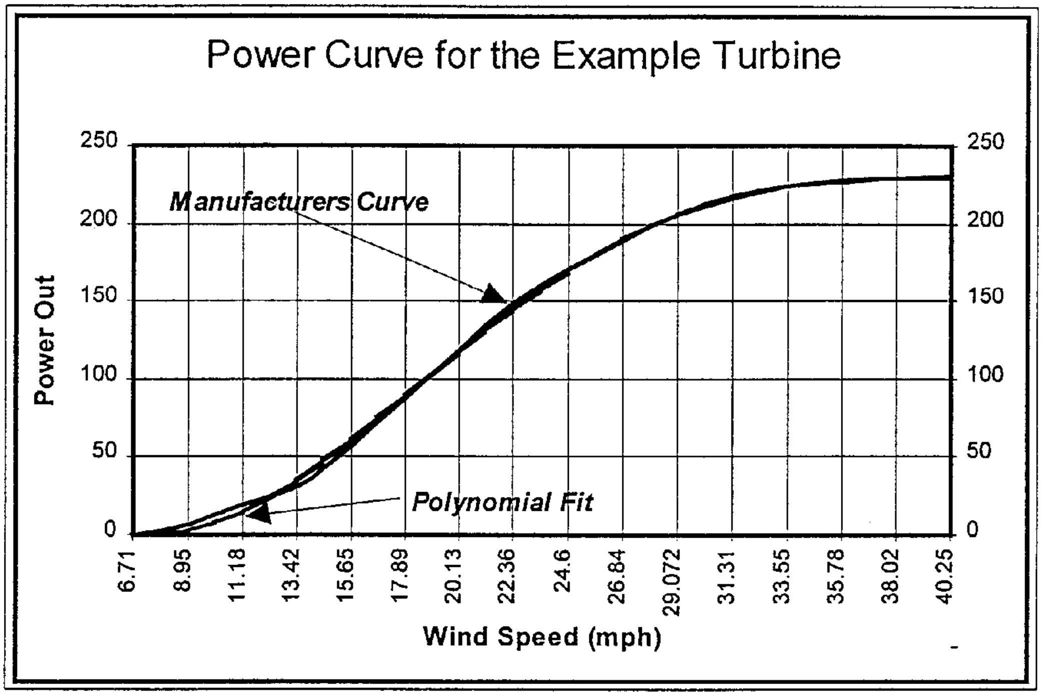


Figure 1. The Manufacturers power curve (the thin, dark, smooth line) and the 4th order polynomial fit to the tabulated data (the thick, gray, jagged line).

The Model

The model was developed in a Microsoft Excel® format. The spreadsheet was set up in it's simplest form with the columns assigned as shown in Table 2 below. While it is possible to have a model such as this run totally externally to the data, the task was not to develop such a model but simply to derive the assessment data.

The first two columns are self explanatory. They simply provide the identifying date and time stamp. The third column is the hourly averaged wind speed data. This data was originally in units of meters/sec but was converted to miles/hour for the convenience of the reader. Column four is the equivalent (time stamped) system load data and constitutes the data that was edited to place the last two months of data (August and September, '90) at the beginning of the file.

This was done in case there was any seasonal component to the annual load or wind profile. Column five is the equivalent wind power out of one example turbine. It is calculated by taking the wind speed data in column three and convoluting it with the fourth order polynomial to the WTG power curve.

The sixth column simply eliminates all WTG power out data below the 5.1kW threshold. Here again, the value of 5.1 could have as easily been 10.1. It was intended to eliminate the questionably low output energy levels. Typically, with the lower wind speeds, the within hour variance is likely to have been high. Therefore, while the average may have been 5.1, there is a high probability that the wind turbine would never have started up because it was not at that speed for long enough uninterrupted periods. The energy contribution, or loss in this case, is so small as to be insignificant.

The seventh, ninth, eleventh and thirteenth columns are written to determine if the addition of one, two, three, or four wind turbines at that output level would reduce the load remaining at the power house to below the minimum set point of 200KW. If the test turns out negative, (the addition of the turbine will not reduce the balance of load on the diesels below the minimum), then the flag in the following column is set to a "1" (turbine allowed to operate). If the addition of that turbine would reduce the load on the diesels below the set point limit, then the flag is set to a "0" (the turbine is not allowed to operate) . The leading and intervening columns, numbers six, eight, ten, and twelve are the power available with one, two, three, or four turbines in operation. The 14^{th} and 15^{th} columns simply sum the number of "1s" in "flag" columns seven, nine, eleven, and thirteen and the total wind power that can be utilized under the minimum set point constraint. The value in column 16 is the number representing the wind turbine power available that is not being utilized (the waste wind energy). Column 17 is the balance of load to be picked up by the diesels and column 18 is the equivalent fuel usage by the diesels. This last value was generated assuming a 13kWh gallon^{-1} rate.

Table 2. Layout of the spread sheet columns.

Column Number	Parameter
1	Julian day
2	Hour
3	Wind Speed Average (mph)*
4	System Load (kW)
5	Power out of one WTG (kW unconstrained)
6	Power out of first WTG (kW constrained**)
7	Test #1 for Excess Power
8	Power out of second WTG (kW constrained**)
9	Test #2 for Excess Power
10	Power out of third WTG (kW constrained**)
11	Test #3 for Excess Power
12	Power out of fourth WTG (kW constrained**)
13	Test #4 for Excess Power
14	Total wind energy allowed on line (kW)
15	Number of turbines on line
16	Waste Wind Energy (kWh not generated due to curtailment of some number of WTGs)
17	Diesel load balance (kW load remaining for the diesels to generate)
18	Diesel fuel consumed (gal) at 13 kWh gal^{-1}

* The wind speed data was converted from m/s to mph for the convenience of the reader that may have no concept of speeds in meters per second.
** The only WTG constraint was simply to set the output of the turbine to zero if the turbine output was below 5kW since the reliability of such a calculation is somewhat questionable

Considerable work has been done to characterize the rate of fuel consumption by diesel engines compared to the percent load on the engine. The results indicate a nearly linear fit with approximately a 25% offset at zero load is appropriate. The operating generator(s) on the islands are never operated below synchronous speed except if they have been taken off line, then they are shut down completely.

The use of the Skarstein-Uhlen equation to accumulate fuel use is justified for high temporal resolution models. However, it is the authors opinion that with only hourly sampled load data, applying such an equation is meaningless. Experience with modern, large, low to intermediate speed, stationary diesels shows that the upper end of the efficiency spectrum might show as much as 15-17 kWh gal^{-1} fuel rate. A record of the fuel utilization on the island was available. The data was in Excel® format and gave the date, the daily energy generated/used in kWh, the engine hours, and the fuel used. When expressed in terms of kWh gal^{-1}, the annual mean value is 11.6 kWh gal^{-1}. Further investigation of the fuel use data seemed to be an exercise in futility. The understanding is that 24 engine hours indicates that at no time was there more than one engine on line. Any higher number indicates that for some portion of the day a number of diesels were running and on line. A multivariate analysis of the available data did not help clear up the picture. The relationship of engine hours, to kWh, to gallons of fuel used over the entire year, was uncorrelated. While one could choose to use the 11.6 kWh gal^{-1} number as the average, the decision was made to use the number 13 kWh gal^{-1}, a more typical value for similar operations familiar to the author. If in fact the real values are lower, such as 11 kWh gal^{-1}, then <u>the value of wind to the system is even greater</u>.

It is important to realize that, though one might expect to see a 200kW diesel load occur frequently in column 17 in this example, the 200kW minimum constraint will not allow the addition of another WTG if that addition would reduce the diesel load ***below*** the 200kW set point (limit). Therefore, the number in column 17 will always be between 200kW and 425kw unless there is no wind power available. It must also be kept in mind that this entire model is based on hourly averaged data. In reality, there is little relationship between these apparent ramp rates with the actual ramp rates. One aspect of the control algorithm that was not incorporated into the present model but was "tested" for specific instances is the appropriate addition of load. The <u>appropriate</u> addition of load would occur when the disparity between the minimum set point and balance of diesel load were such that adding some load would allow another wind turbine to come on line thereby reducing the diesel load back to it's set point.

For example; assume that the wind is such that the example wind turbines would be putting out about 200kW; and the system load balance (after reduction by the wind) is 300kW. The addition of another turbine would reduce the load balance to be picked up by the diesel to ~100kW - below the minimum set point assumed to be 200kW. Now, if the control strategy added ~ 100 kW of load to the system, the load balance would be increased to 400kW thus allowing the addition of another wind turbine while reducing the balance of load on the diesel(s) to 200kW (from 300kW), a reduction of 100kW load and ~8 gallons of fuel based on hourly averages.

Figure 2 shows one of the model results for a six day period at the beginning of the file. The purpose of the figure is to show how the combination of wind and load governs the operation (on/off) of each of the four wind turbines. While Figure 2 provides a graphical representation of the operation of the wind turbines, the amount of wind energy that is being used is not indicated and the explanation of some of the operations is, thus, obscured. To provide some enlightenment, Figure 3 furnishes a time series chart depicting both the wind energy being used (bottom line bounding the shaded area) in the system and the total system load (top line bounding the shaded area).

The wind energy <u>used</u> (from column 14 of the spread sheet) is not necessarily the wind energy available. There are exceptions such as in cases where the bottom line on the chart goes to zero when there is more than 200kW load. To help clarify the content of Figures 2 and 3, the reader is asked to look at the region of each chart on late Julian day 213 and early day 214. There is a period of about ten hours on both charts that appear as a relatively flat floored valley. In Figure 2, the period shows that only one turbine was in operation during the interval. During that same period on Figure 3, it is evident that the single turbine was producing around it's rated power of 225 kW. If the operating strategy allowed a second turbine to come on line, the balance of load remaining for the diesel(s) to pick up would have been less than 100kW. Therefore, the test for excess power for the second turbine was positive and a second turbine was not allowed to come on line.

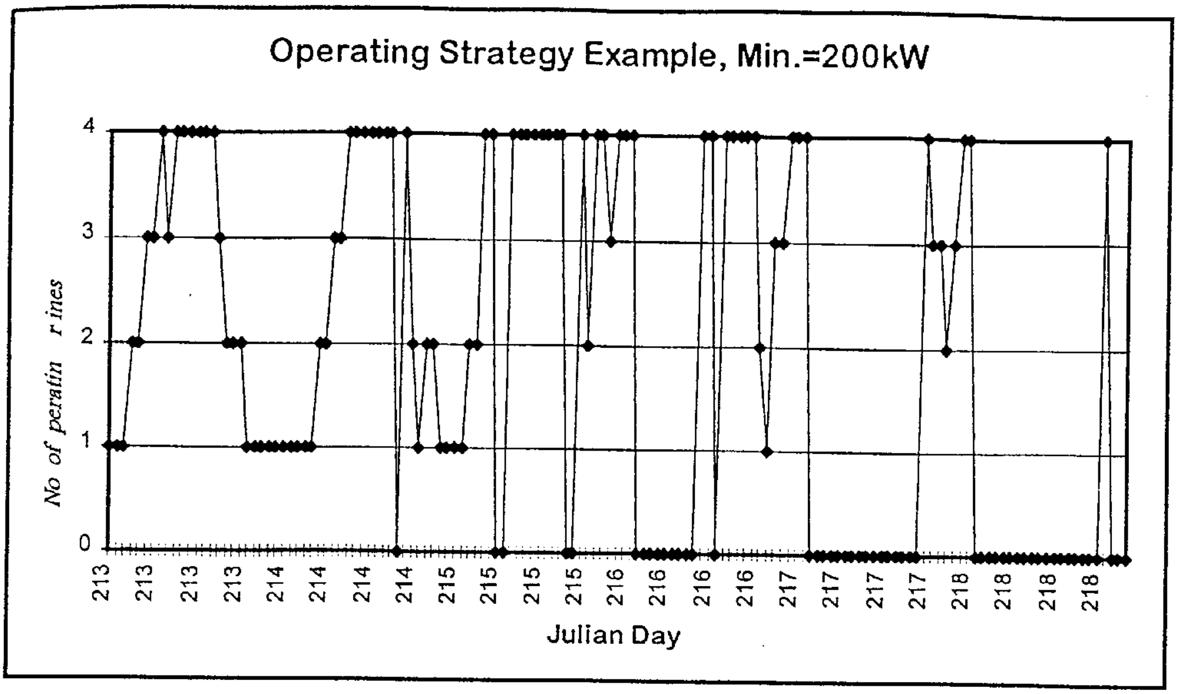


Figure 2. Chart showing the number of wind turbines operating during each hour for a six day period in early August. Each diamond represents an hour. The numbers on the abscissa are the Julian Day and are repeated every four hours. This chart does not provide any indication of the wind energy utilization.

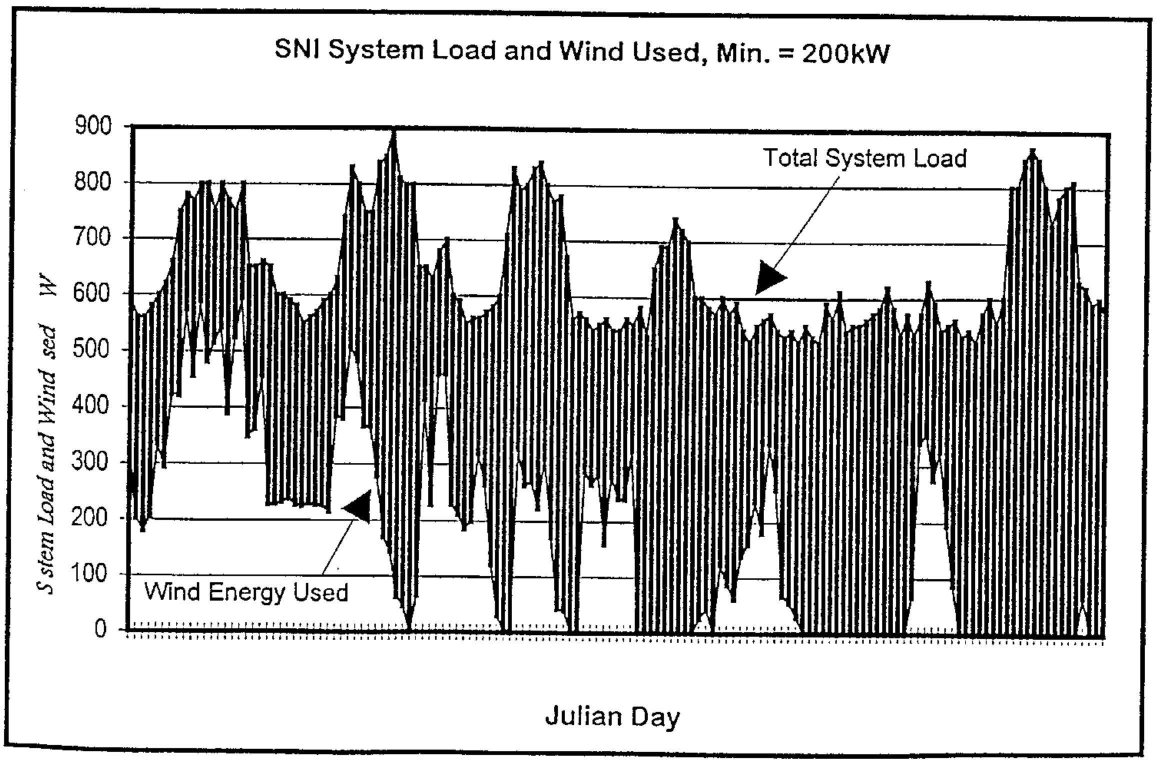


Figure 3. A time series plot of the total system load (top line) and the wind energy being used by the system (bottom line) during the same period. The area in the chart that is darkened is the portion of the load that the diesel generators would have to pick up and the clear area from the x-axis to the darkened area constitutes the load picked up by the wind turbines.

Figures 4 and 5, below, are added to show the effect of changing the minimum set point to 100kW. Figure 4 shows that the number of hours during the period when only one turbine was running under the 200kW set point have been significantly reduced with the lower set point. Note also in Figure 5, that the broad, flat floored valley during late day 213 and early day 214 has become a single hour that the diesels will have to pick up. For clarity, Figure 6 shows what the wind speed was doing during the same period. As can be seen, when there are zero wind turbines operating in both Figures 2 and 4, it is not because of low loads but rather low to no wind. Recall that the power out of the wind turbine below about 10 miles per hour is nil.

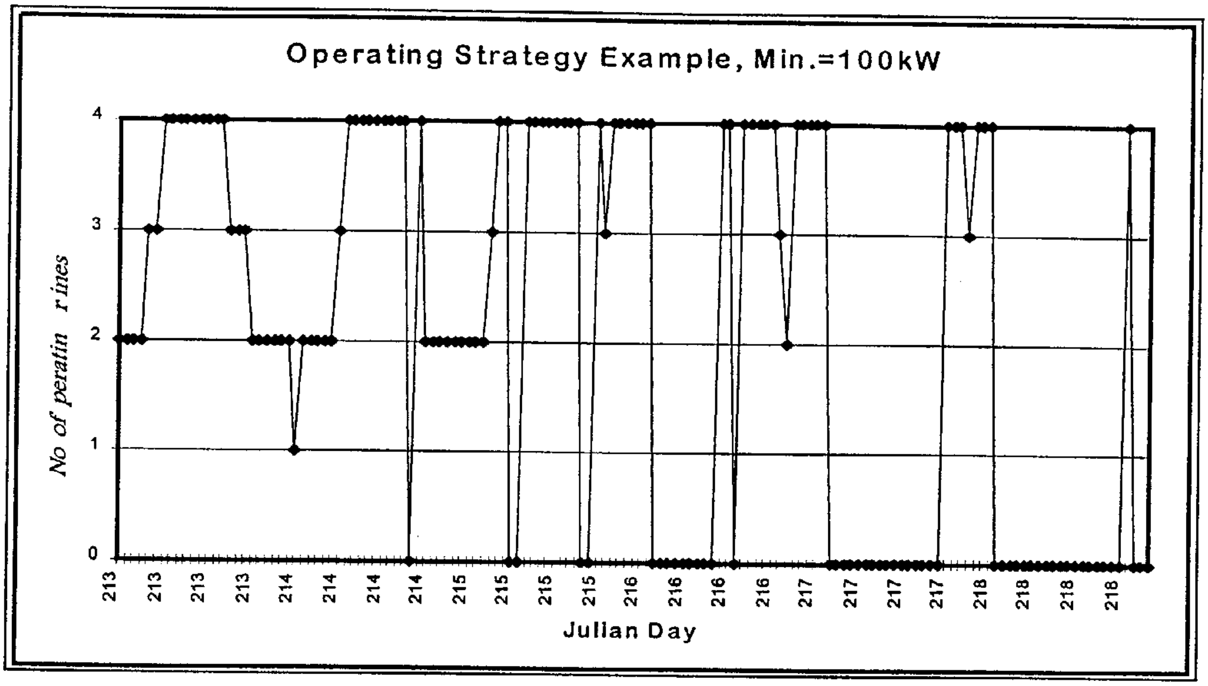


Figure 4. Similar to Figure 2 but with the minimum set-point for the diesel load at 100 kW. Note that the period of time on late day 213 and early day 214 allows a second turbine to operate for 12 of 13 hours.

The Economics of Wind Energy on SNI.

The economics of a wind energy project can become quite complex due to financing arrangements. It is assumed for this exercise that the wind energy project is bought and paid for as a capitol development by the Navy. While that simplifies the calculation considerably, there are sufficient unknowns that some values are, at best, estimates. Here again, the estimates are reasonably conservative.

The cost, per turbine, installed on the island, is assumed to be \$337,500.00 in 1996 dollars. This value simply assumes the cost is \$1500.00 per kW installed. While this appears to be an above market price, the costs of installing this small number of turbines on off-shore islands is going to be fairly high since there would be a requirement for the contractor to provide and ship to the island all the necessary heavy equipment including a portable concrete batch plant. This number may be excessively high but, again, it is conservative. The cost of the entire installation of four turbines is about \$1,350,000.00 total. Electrical infrastructure and control systems are additional but are a relatively small portion of the total cost. The life expectancy for these turbines according to Navy criteria, is to be 20 years[1] and thus, the per year amortization amounts to ~\$67,500 PA

[1] In the wind energy industry, the presumed and design life is typically 30 years however the Navy has made the assumption that the wind turbines will have a life expectancy of only 20 years.

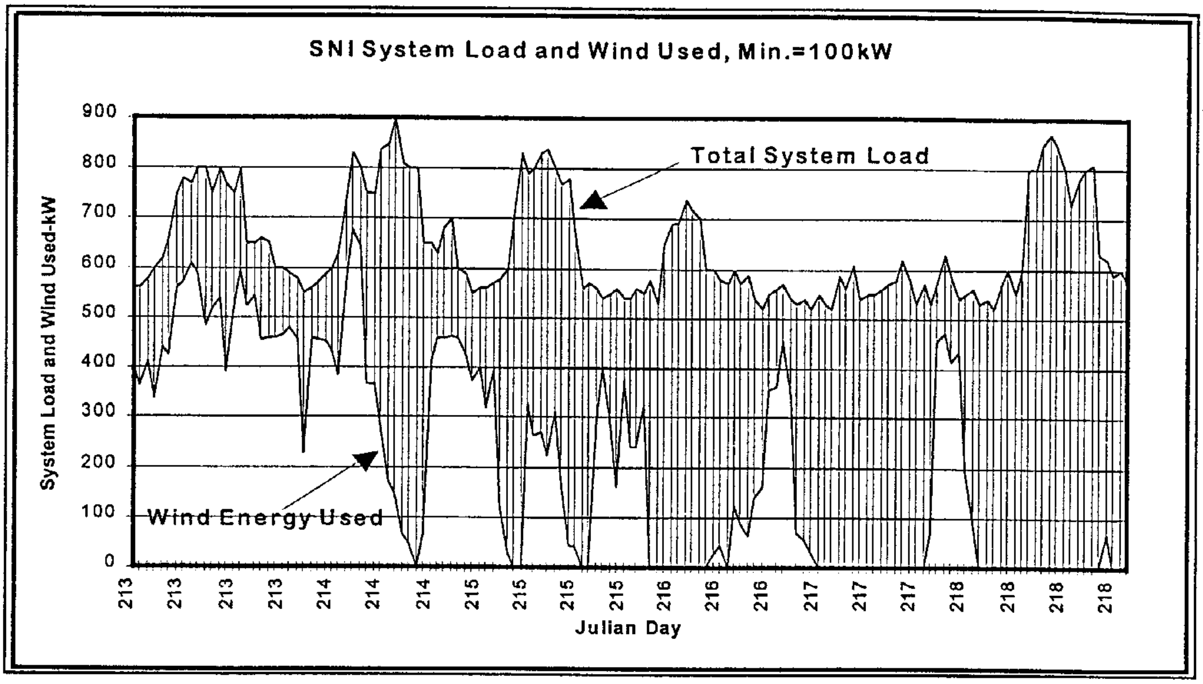


Figure 5. Similar to Figure 3 but with the minimum set-point for the diesel load at 100kW.

The diesel fuel cost, or in the case of San Nicolas, the cost of JP-5[2], their reported fuel of choice, was determined to be ~ $1.14 gal.$^{-1}$ at the site. This value includes a 5¢ charge for administrative handling. Numbers such as this can easily be changed in the model. An additional charge associated with the cost of fuel is the cost of cleaning the barge tanks with each shipment. That cost is $25,000 per barge load. This charge is incurred ~10 times per year for a total cost of $250,000.

The diesel power plant also has certain costs. While the original capital costs are ignored here, a "sinking fund" is established to provide for the replacement of the engines. The life of such engines is set at 10 years and the cost of replacement is estimated to be about $700.00/kW or $2,450,000 for all five engines. Amortized over 10 years this is simply taken as $245,000/year. Another charge that needs to be added to the O&M costs for the diesel plant is a $250,000/year contract for overhaul of all five engines after 2000 run-hours. This charge has apparently been nearly annual in the past but is pegged to the 2000 hour run time and is, therefore, less with the addition of wind energy. For the year 1989, the total number of engine hours was 9983 hours, essentially 10,000 hours. With the addition of wind, the number of hours the diesels operate is presumed to be reduced by the ratio of kWh without wind to that with wind. The overhaul contract costs on an annual basis would be reduced to $186,630 if the minimum set point for the diesel plant was 200kW and further reduced to $172,120 if the minimum can be set to 100kW.

A very serious consideration concerning the diesel plant and one of the major differences between the HYBRID2 model and this simple spread sheet is fuel use. The HYBRID2 model incorporates a built-in function that calculates the diesel fuel utilization. This function is based on published observations and is a linear function of load with an offset at zero load (idle speed). This is a good example of an attribute of the model that is appropriate with sub-hourly data and a smaller system but is questionable with only hourly averaged data and a large system. In the spread sheet model, and in reality, the engines are never at idle or shut off unless there is another on line. Therefore a simple value for the kWh/gal was assigned based on the best available information and experience with other similar sites and was not calculated via the function .

[2] The diesel engine manufacturers recommend that a "chiller" be added to JP-5 to increase it's lubricity and reduce wear on the fuel pump, the injection pump and the injectors.

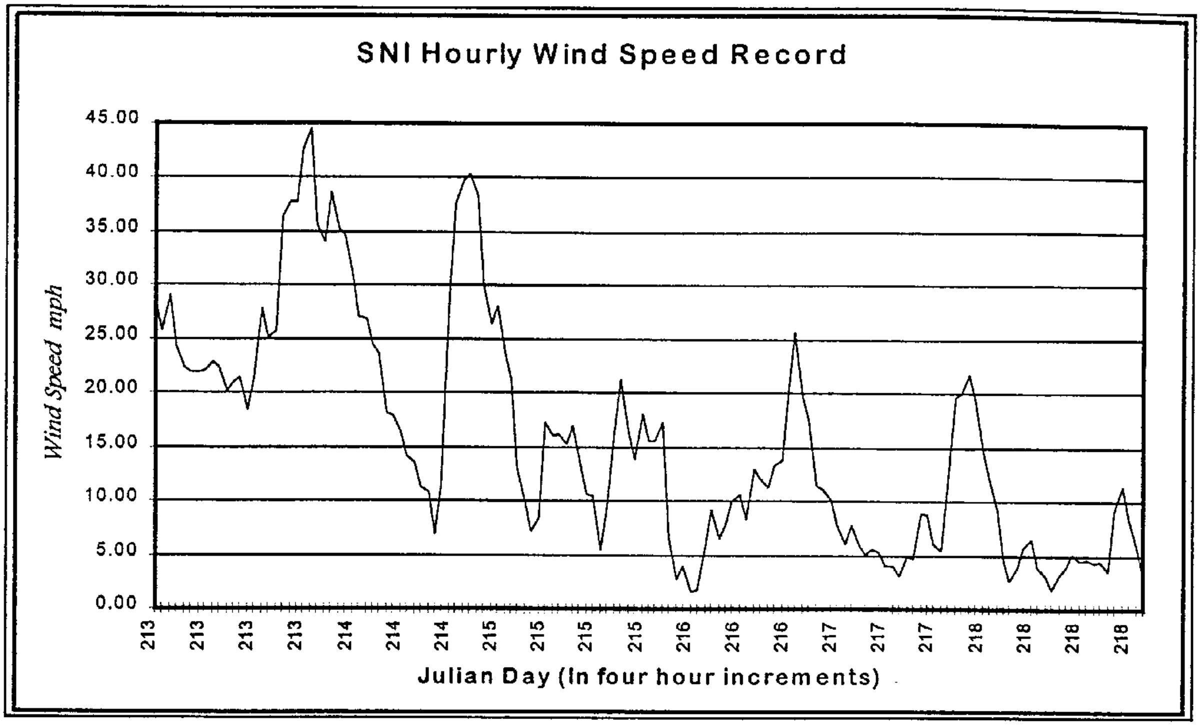


Figure 6. Time series plot of the wind speed during the same period of time as that shown in figures 2,3,4,and 5.

The Results

Included as an addendum to this report is a copy of the actual spread sheet on 3.5" diskettes. By simply convolving the wind speed to the power curve of the wind turbine for all 8760 hours of the year one gets the number of kWh you might expect assuming 100% availability of the wind turbine. In this exercise, there is no arbitrary assignment of WTG availability. It is the authors contention that it is meaningless to assign an availability since 1) there are sufficient lulls in the wind to perform most maintenance functions and 2) with a constrained, four WTG plant there is nearly always a "spare" turbine to replace one that might be down for some longer duration maintenance. A third and final point would be that today's wind turbines are exhibiting an availability of >97-98%. Therefore, availability deems to be a "non-issue" in this circumstance. If desired, some sort of Monte Carlo simulation of turbine outages based on experience could easily be added. Also, there were no deductions for losses due to "Array Effects" since there were only to be four wind turbines and the wind has a prevailing direction. Siting of a four turbine array under these circumstances should be straight forward enough to be able to avoid any such effects. There will be some electrical losses in the lines and transformers but these are small enough that the conservative approach to this entire analysis probably has them covered

The result of convoluting the wind speed data with the example wind turbine power curve is that a single turbine should produce about 675,000 kilowatt hours of energy per year at the San Nicolas Island site for the year modeled. That is equal to a capacity factor of 34.2% - a number that tends to indicate the resource at the site is extremely good. Again, assuming no artificial availability numbers, with all four turbines allowed to run unconstrained the production swells to 2.7 million kilowatt hours. In fact, however, assuming the constraints imposed by the operating strategy requiring a minimum 200kW load for the diesel(s), the combined, usable energy production of the four wind turbines is only about 1.43 million kWh of energy for the year. The result of re-running the model using a 100kW minimum load constraint showed that the number of usable kWh increases to 1.75 million. The reduction in cost is most easily seen as the fuel cost per kWh (saved) plus the O&M cost/kWh minus the added cost of O&M on the wind turbine. Table 3, below summarizes the best estimates of the apparent cost savings.

Figure 7 shows the number of hours that each of four turbines would be running during the year with the 200kW minimum diesel constraint. This is taken directly from the model data and indicates that out of one year (8760 hours) nearly 7400 hours had sufficient wind and system load to have at least one wind turbine running, monotonically decreasing to about 4500 hours with sufficient wind and system load for four turbines to be operating.

Table 3. Summary of costs and savings assuming the 200kW minimum set point.

Item	Without Wind Turbines	With Wind Turbines
Wind Turbine O&M/Yr. @0.01/kWh	$0.00	$14,305.45
Diesel O&M/Yr. @0.066/kWh	$375,863.76	$278061.61
Diesel Fuel Costs @ $1.14/gal	$494,900.31	$369,452.49
Annual Amortization of Wind Turbines	$0.00	$67,500.00
Sinking Fund to Replace Diesels	$210,000.00	$210,999.00
2000 hour Engine Overhauls	$250,000.00	**$186,629.75
Totals	$$1,330,764.07	$1,125,949.30
Savings		$204,814.76

** With the set point at 100kW, this number becomes $172,118.74 and the total savings become $ 266,396.14.

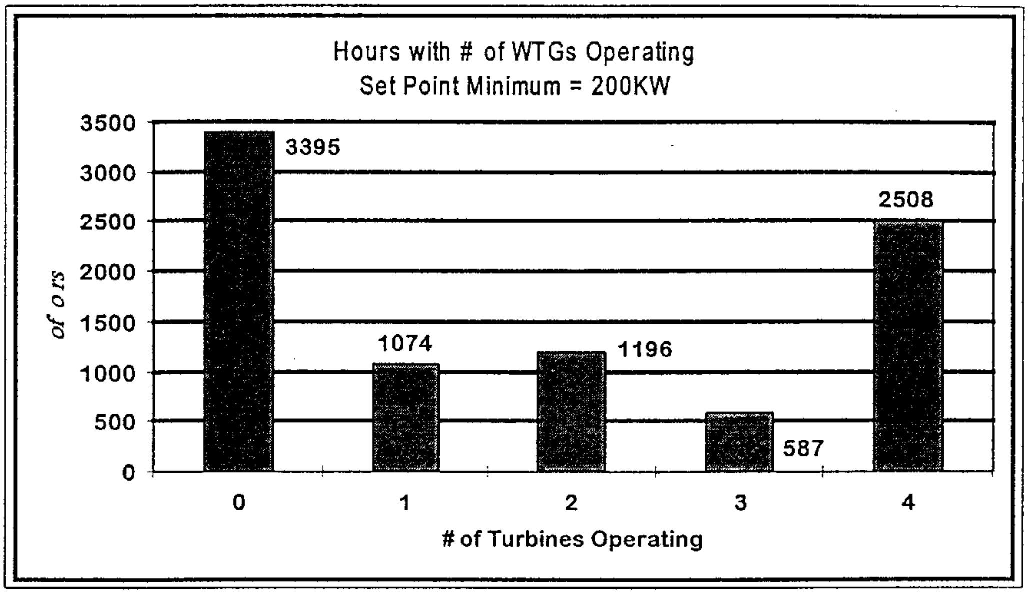


Figure 7. A Histogram of the number of hours that each of the four available WTG would operate with the operating strategy modeled herein.

The difference in the estimates is between $205,000 to $266,000 per year saved by adding the four wind turbines. This equates to amortizing one wind turbine every 1.6 or 1.4 years depending on the minimum set point. This seems to provide a good rate of return of investment .

For completeness sake Figure 8, shown below, is similar to figure 7 but with the minimum diesel constraint set to 100Kw.

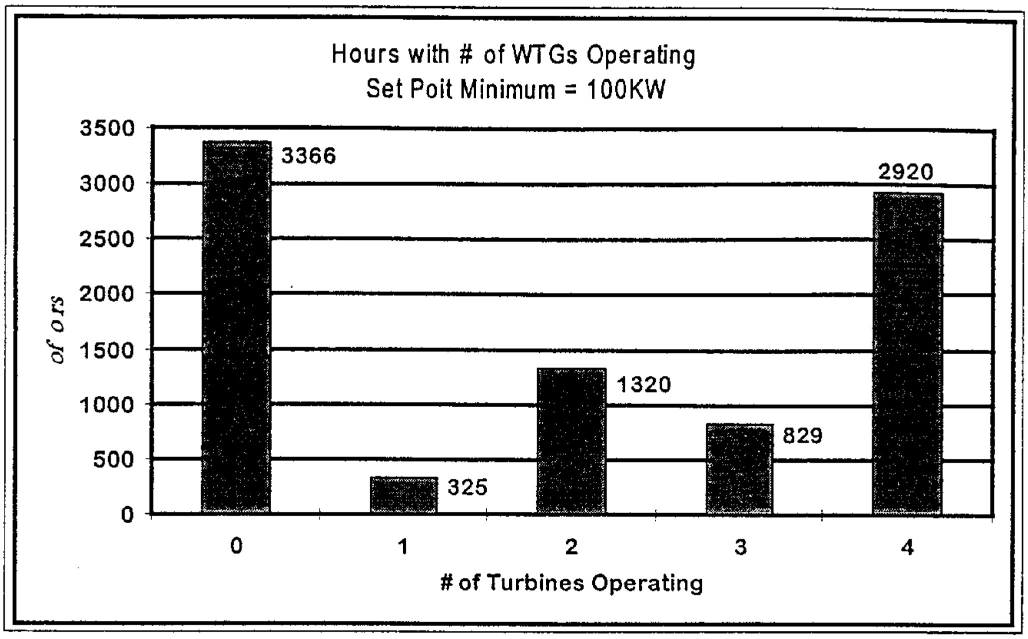


Figure 8. A Histogram of the number of hours that each of the four available WTG would operate with the operating strategy minimum set to 100

Conclusions

Although it is too early to make very bold statements, it appears that this simple wind/diesel model performs quite adequately for the purpose that it is intended. Students getting into the higher mathematics of college frequently do not comprehend the difference between resolution and accuracy. The simple spreadsheet model described herein has all the resolution the data can justify. The accuracy is a question but is certainly within the 10% region. A model such as HYBRID2, afforded the luxury of high temporal resolution data and more quantitative data on such things as fuel utilization, may provide a clearer look into the minute by minute operational details but the accuracy relative to reality is also a question. With the low rate data available for this investigation, the HYBRID2 model is clearly an over-kill and probably can not produce any better (more accurate) results.

The Navy has expressed concern over the potential of a wind power plant experiencing large scale changes in output very rapidly thus causing the diesels to work harder to follow load. While this task does not include the documentation of such, it is well documented that the stronger the average winds, the lower the variance and conversely, the lower the average winds, the higher the variance, percentage-wise. Further, there has been expressed the concern that the jitter or variance in the wind will add to the variance in the load. While this has never been documented to the best of the authors knowledge, the one thing that has been documented is that when multiple WTGs are on line, their long term mean power is strictly additive while the variances add as the reciprocal of the number of turbines. It is logical that when considering a "noisy source" (the WTGs) interacting with a "noisy sink" (the load), their variances must at least partially cancel. It would be a worthwhile exercise to take a short period (i.e. a week) of high resolution ($1sec^{-1}$) wind speed and direction data and synonymous load data at the island to investigate the apparent effects of adding wind to the San Nicolas Island power system and might be considered a mandatory first step.

APPENDIX D: Wind-Diesel System Operational Guidelines

This appendix contains the wind-diesel system operational guidelines that lead to the overall operational scenario. This scenario was developed by NREL and its sub-contractors for the SERDP-funded San Clemente Island wind turbine installation.

This appendix conveys information on the amount of wind turbine electrical energy that can be utilized with the SCI diesel system and on the appropriate use of external loads to manage excess wind energy. Fuel savings are still achievable with low demand when the wind-diesel system includes a 225 kW load bank.

	WIND SPEED (mph)											
DEMAND	10				15				20			
LOAD (kW)	#WG	WG (kW)	DG (kW)	LB (kW)	#WG	WG (kW)	DG (kW)	LB (kW)	#WG	WG (kW)	DG (kW)	LB (kW)
400	1	19.5	380.5	0.0	1	57.1	342.9	0.0	1	118.7	281.3	0.0
	2	39.0	361.0	0.0	2	114.2	285.8	0.0	2	237.4	162.6	0.0
	3	58.5	341.5	0.0	3	171.3	228.7	0.0	3	356.1	118.9	75.0
	4	78.0	322.0	0.0	4	228.4	171.6	0.0	4	474.8	150.2	225.0
500	1	19.5	480.5	0.0	1	57.1	442.9	0.0	1	118.7	381.3	0.0
	2	39.0	461.0	0.0	2	114.2	385.8	0.0	2	237.4	262.6	0.0
	3	58.5	441.5	0.0	3	171.3	328.7	0.0	3	356.1	143.9	0.0
	4	78.0	422.0	0.0	4	228.4	271.6	0.0	4	474.8	100.2	75.0
600	1	19.5	580.5	0.0	1	57.1	542.9	0.0	1	118.7	481.3	0.0
	2	39.0	561.0	0.0	2	114.2	485.8	0.0	2	237.4	362.6	0.0
	3	58.5	541.5	0.0	3	171.3	428.7	0.0	3	356.1	243.9	0.0
	4	78.0	522.0	0.0	4	228.4	371.6	0.0	4	474.8	125.2	0.0
700	1	19.5	680.5	0.0	1	57.1	642.9	0.0	1	118.7	581.3	0.0
	2	39.0	661.0	0.0	2	114.2	585.8	0.0	2	237.4	462.6	0.0
	3	58.5	641.5	0.0	3	171.3	528.7	0.0	3	356.1	343.9	0.0
	4	78.0	622.0	0.0	4	228.4	471.6	0.0	4	474.8	225.2	0.0
800	1	19.5	780.5	0.0	1	57.1	742.9	0.0	1	118.7	681.3	0.0
	2	39.0	761.0	0.0	2	114.2	685.8	0.0	2	237.4	562.6	0.0
	3	58.5	741.5	0.0	3	171.3	628.7	0.0	3	356.1	443.9	0.0
	4	78.0	722.0	0.0	4	228.4	571.6	0.0	4	474.8	325.2	0.0
900	1	19.5	880.5	0.0	1	57.1	842.9	0.0	1	118.7	781.3	0.0
	2	39.0	861.0	0.0	2	114.2	785.8	0.0	2	237.4	662.6	0.0
	3	58.5	841.5	0.0	3	171.3	728.7	0.0	3	356.1	543.9	0.0
	4	78.0	822.0	0.0	4	228.4	671.6	0.0	4	474.8	425.2	0.0
1000	1	19.5	980.5	0.0	1	57.1	942.9	0.0	1	118.7	881.3	0.0
	2	39.0	961.0	0.0	2	114.2	885.8	0.0	2	237.4	762.6	0.0
	3	58.5	941.5	0.0	3	171.3	828.7	0.0	3	356.1	643.9	0.0
	4	78.0	922.0	0.0	4	228.4	771.6	0.0	4	474.8	525.2	0.0
1100	1	19.5	1,080.5	0.0	1	57.1	1,042.9	0.0	1	118.7	981.3	0.0
	2	39.0	1,061.0	0.0	2	114.2	985.8	0.0	2	237.4	862.6	0.0
	3	58.5	1,041.5	0.0	3	171.3	928.7	0.0	3	356.1	743.9	0.0
	4	78.0	1,022.0	0.0	4	228.4	871.6	0.0	4	474.8	625.2	0.0
1200	1	19.5	1,180.5	0.0	1	57.1	1,142.9	0.0	1	118.7	1,081.3	0.0
	2	39.0	1,161.0	0.0	2	114.2	1,085.8	0.0	2	237.4	962.6	0.0
	3	58.5	1,141.5	0.0	3	171.3	1,028.7	0.0	3	356.1	843.9	0.0
	4	78.0	1,122.0	0.0	4	228.4	971.6	0.0	4	474.8	725.2	0.0
1300	1	19.5	1,280.5	0.0	1	57.1	1,242.9	0.0	1	118.7	1,181.3	0.0
	2	39.0	1,261.0	0.0	2	114.2	1,185.8	0.0	2	237.4	1,062.6	0.0
	3	58.5	1,241.5	0.0	3	171.3	1,128.7	0.0	3	356.1	943.9	0.0
	4	78.0	1,222.0	0.0	4	228.4	1,071.6	0.0	4	474.8	825.2	0.0
1400	1	19.5	1,380.5	0.0	1	57.1	1,342.9	0.0	1	118.7	1,281.3	0.0
	2	39.0	1,361.0	0.0	2	114.2	1,285.8	0.0	2	237.4	1,162.6	0.0
	3	58.5	1,341.5	0.0	3	171.3	1,228.7	0.0	3	356.1	1,043.9	0.0
	4	78.0	1,322.0	0.0	4	228.4	1,171.6	0.0	4	474.8	925.2	0.0
1500	1	19.5	1,480.5	0.0	1	57.1	1,442.9	0.0	1	118.7	1,381.3	0.0
	2	39.0	1,461.0	0.0	2	114.2	1,385.8	0.0	2	237.4	1,262.6	0.0
	3	58.5	1,441.5	0.0	3	171.3	1,328.7	0.0	3	356.1	1,143.9	0.0
	4	78.0	1,422.0	0.0	4	228.4	1,271.6	0.0	4	474.8	1,025.2	0.0

KEY

#WG : NUMBER OF WIND GENERATORS
WG : WIND GENERATOR LOAD PRODUCTION (kW)
DG : DIESEL GENERATOR LOAD PRODUCTION (kW)
LB : LOAD BANK LOAD DISSIPATION (kW)

	WIND SPEED (mph)											
DEMAND	25				30				35			
LOAD (kW)	#WG	WG (kW)	DG (kW)	LB (kW)	#WG	WG (kW)	DG (kW)	LB (kW)	#WG	WG (kW)	DG (kW)	LB (kW)
400	1	171.4	228.6	0.0	1	206.0	194.0	0.0	1	227.0	173.0	0.0
	2	342.8	132.2	75.0	2	412.0	138.0	150.0	2	454.0	171.0	225.0
	3	514.2	110.8	225.0	3	OFF			3	OFF		
	4	OFF			4	OFF			4	OFF		
500	1	171.4	328.6	0.0	1	206.0	294.0	0.0	1	227.0	273.0	0.0
	2	342.8	157.2	0.0	2	412.0	163.0	75.0	2	454.0	121.0	75.0
	3	514.2	135.8	150.0	3	618.0	107.0	225.0	3	OFF		
	4	OFF			4	OFF			4	OFF		
600	1	171.4	428.6	0.0	1	206.0	394.0	0.0	1	227.0	373.0	0.0
	2	342.8	257.2	0.0	2	412.0	188.0	0.0	2	454.0	146.0	0.0
	3	514.2	160.8	75.0	3	618.0	132.0	150.0	3	681.0	144.0	225.0
	4	685.6	139.4	225.0	4	OFF			4	OFF		
700	1	171.4	528.6	0.0	1	206.0	494.0	0.0	1	227.0	473.0	0.0
	2	342.8	357.2	0.0	2	412.0	288.0	0.0	2	454.0	246.0	0.0
	3	514.2	185.8	0.0	3	618.0	157.0	75.0	3	681.0	169.0	150.0
	4	685.6	164.4	150.0	4	824.0	101.0	225.0	4	OFF		
800	1	171.4	628.6	0.0	1	206.0	594.0	0.0	1	227.0	573.0	0.0
	2	342.8	457.2	0.0	2	412.0	388.0	0.0	2	454.0	346.0	0.0
	3	514.2	285.8	0.0	3	618.0	182.0	0.0	3	681.0	119.0	0.0
	4	685.6	114.4	0.0	4	824.0	126.0	150.0	4	908.0	117.0	225.0
900	1	171.4	728.6	0.0	1	206.0	694.0	0.0	1	227.0	673.0	0.0
	2	342.8	557.2	0.0	2	412.0	488.0	0.0	2	454.0	446.0	0.0
	3	514.2	385.8	0.0	3	618.0	282.0	0.0	3	681.0	219.0	0.0
	4	685.6	214.4	0.0	4	824.0	151.0	75.0	4	908.0	142.0	150.0
1000	1	171.4	828.6	0.0	1	206.0	794.0	0.0	1	227.0	773.0	0.0
	2	342.8	657.2	0.0	2	412.0	588.0	0.0	2	454.0	546.0	0.0
	3	514.2	485.8	0.0	3	618.0	382.0	0.0	3	681.0	319.0	0.0
	4	685.6	314.4	0.0	4	824.0	176.0	0.0	4	908.0	167.0	75.0
1100	1	171.4	928.6	0.0	1	206.0	894.0	0.0	1	227.0	873.0	0.0
	2	342.8	757.2	0.0	2	412.0	688.0	0.0	2	454.0	646.0	0.0
	3	514.2	585.8	0.0	3	618.0	482.0	0.0	3	681.0	419.0	0.0
	4	685.6	414.4	0.0	4	824.0	276.0	0.0	4	908.0	192.0	0.0
1200	1	171.4	1,028.6	0.0	1	206.0	994.0	0.0	1	227.0	973.0	0.0
	2	342.8	857.2	0.0	2	412.0	788.0	0.0	2	454.0	746.0	0.0
	3	514.2	685.8	0.0	3	618.0	582.0	0.0	3	681.0	519.0	0.0
	4	685.6	514.4	0.0	4	824.0	376.0	0.0	4	908.0	292.0	0.0
1300	1	171.4	1,128.6	0.0	1	206.0	1,094.0	0.0	1	227.0	1,073.0	0.0
	2	342.8	957.2	0.0	2	412.0	888.0	0.0	2	454.0	846.0	0.0
	3	514.2	785.8	0.0	3	618.0	682.0	0.0	3	681.0	619.0	0.0
	4	685.6	614.4	0.0	4	824.0	476.0	0.0	4	908.0	392.0	0.0
1400	1	171.4	1,228.6	0.0	1	206.0	1,194.0	0.0	1	227.0	1,173.0	0.0
	2	342.8	1,057.2	0.0	2	412.0	988.0	0.0	2	454.0	946.0	0.0
	3	514.2	885.8	0.0	3	618.0	782.0	0.0	3	681.0	719.0	0.0
	4	685.6	714.4	0.0	4	824.0	576.0	0.0	4	908.0	492.0	0.0
1500	1	171.4	1,328.6	0.0	1	206.0	1,294.0	0.0	1	227.0	1,273.0	0.0
	2	342.8	1,157.2	0.0	2	412.0	1,088.0	0.0	2	454.0	1,046.0	0.0
	3	514.2	985.8	0.0	3	618.0	882.0	0.0	3	681.0	819.0	0.0
	4	685.6	814.4	0.0	4	824.0	676.0	0.0	4	908.0	592.0	0.0

KEY

#WG : NUMBER OF WIND GENERATORS
WG : WIND GENERATOR LOAD PRODUCTION (kW)
DG : DIESEL GENERATOR LOAD PRODUCTION (kW)
LB : LOAD BANK LOAD DISSIPATION (kW)

	WIND SPEED (mph)			
DEMAND	40			
LOAD (kW)	#WG	WG (kW)	DG (kW)	LB (kW)
400	1	230.0	170.0	0.0
	2	460.0	165.0	225.0
	3	OFF		
	4	OFF		
500	1	230.0	270.0	0.0
	2	460.0	115.0	75.0
	3	OFF		
	4	OFF		
600	1	230.0	370.0	0.0
	2	460.0	140.0	0.0
	3	690.0	135.0	225.0
	4	OFF		
700	1	230.0	470.0	0.0
	2	460.0	240.0	0.0
	3	690.0	160.0	150.0
	4	OFF		
800	1	230.0	570.0	0.0
	2	460.0	340.0	0.0
	3	690.0	110.0	0.0
	4	920.0	105.0	225.0
900	1	230.0	670.0	0.0
	2	460.0	440.0	0.0
	3	690.0	210.0	0.0
	4	920.0	130.0	150.0
1000	1	230.0	770.0	0.0
	2	460.0	540.0	0.0
	3	690.0	310.0	0.0
	4	920.0	155.0	75.0
1100	1	230.0	870.0	0.0
	2	460.0	640.0	0.0
	3	690.0	410.0	0.0
	4	920.0	180.0	0.0
1200	1	230.0	970.0	0.0
	2	460.0	740.0	0.0
	3	690.0	510.0	0.0
	4	920.0	280.0	0.0
1300	1	230.0	1,070.0	0.0
	2	460.0	840.0	0.0
	3	690.0	610.0	0.0
	4	920.0	380.0	0.0
1400	1	230.0	1,170.0	0.0
	2	460.0	940.0	0.0
	3	690.0	710.0	0.0
	4	920.0	480.0	0.0
1500	1	230.0	1,270.0	0.0
	2	460.0	1,040.0	0.0
	3	690.0	810.0	0.0
	4	920.0	580.0	0.0

KEY

#WG : NUMBER OF WIND GENERATORS
WG : WIND GENERATOR LOAD PRODUCTION (kW)
DG : DIESEL GENERATOR LOAD PRODUCTION (kW)
LB : LOAD BANK LOAD DISSIPATION (kW)

INPUT

WIND SPEED (mph)	GEN LOAD (kW)	DG LOAD MIN (kW)	DG INC (kW)
10	19.5	100.0	75.0
15	57.1		
20	118.7		
25	171.4		
30	206.0		
35	227.0		
40	230.0		

105.0

NREL: SAN CLEMENTE ISLAND

FUEL CONSUMPTION ESTIMATE

	WIND SPEED (10 mph)					
DEMAND LOAD (kW)	#WG	WG (kW)	DG (kW)	FUEL DEMAND (gal/hr)	FUEL USED (gal/hr)	FUEL SAVED (gal/hr)
800	1	19.5	780.5	51.6	50.3	1.3
	2	39.0	761.0	51.6	48.8	2.8
	3	58.5	741.5	51.6	47.7	3.9
	4	78.0	722.0	51.6	46.7	4.9

	WIND SPEED (15 mph)					
DEMAND LOAD (kW)	#WG	WG (kW)	DG (kW)	FUEL DEMAND (gal/hr)	FUEL USED (gal/hr)	FUEL SAVED (gal/hr)
800	1	57.1	742.9	51.6	47.8	3.8
	2	114.2	685.8	51.6	44.8	6.8
	3	171.3	628.7	51.6	41.7	9.9
	4	228.4	571.6	51.6	38.6	13.0

	WIND SPEED (20 mph)					
DEMAND LOAD (kW)	#WG	WG (kW)	DG (kW)	FUEL DEMAND (gal/hr)	FUEL USED (gal/hr)	FUEL SAVED (gal/hr)
800	1	118.7	681.3	51.6	44.5	7.1
	2	237.4	562.6	51.6	38.2	13.4
	3	356.1	443.9	51.6	31.8	19.8
	4	474.8	325.2	51.6	25.4	26.2

	WIND SPEED (25 mph)					
DEMAND LOAD (kW)	#WG	WG (kW)	DG (kW)	FUEL DEMAND (gal/hr)	FUEL USED (gal/hr)	FUEL SAVED (gal/hr)
800	1	171.4	628.6	51.6	41.7	9.9
	2	342.8	457.2	51.6	32.5	19.1
	3	514.2	285.8	51.6	23.5	28.1
	4	685.6	114.4	51.6	16.6	35.0

	WIND SPEED (30 mph)					
DEMAND LOAD (kW)	#WG	WG (kW)	DG (kW)	FUEL DEMAND (gal/hr)	FUEL USED (gal/hr)	FUEL SAVED (gal/hr)
800	1	206.0	594.0	51.6	39.8	11.8
	2	412.0	388.0	51.6	28.8	22.8
	3	618.0	182.0	51.6	19.3	32.3
	4	824.0	126.0	51.6	17.1	34.5

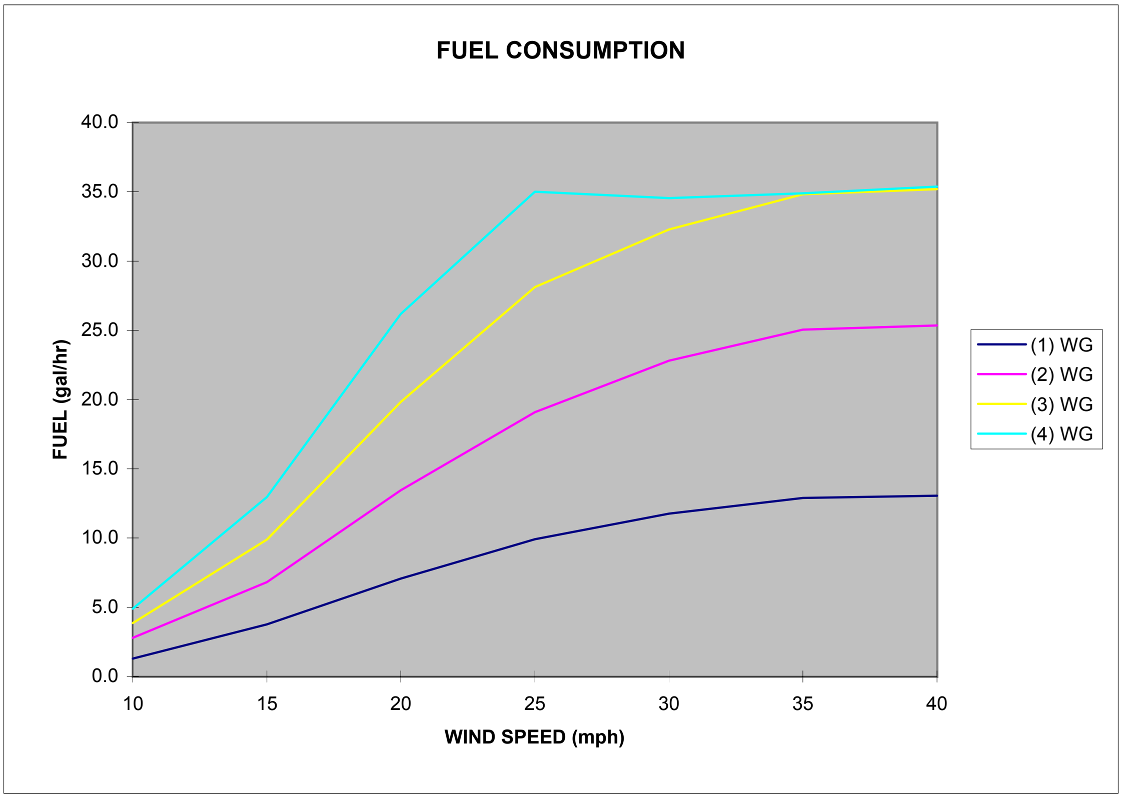
	WIND SPEED (35 mph)					
DEMAND LOAD (kW)	#WG	WG (kW)	DG (kW)	FUEL DEMAND (gal/hr)	FUEL USED (gal/hr)	FUEL SAVED (gal/hr)
800	1	227.0	573.0	51.6	38.7	12.9
	2	454.0	346.0	51.6	26.6	25.0
	3	681.0	119.0	51.6	16.8	34.8
	4	908.0	117.0	51.6	16.7	34.9

	WIND SPEED (40 mph)					
DEMAND LOAD (kW)	#WG	WG (kW)	DG (kW)	FUEL DEMAND (gal/hr)	FUEL USED (gal/hr)	FUEL SAVED (gal/hr)
800	1	230.0	570.0	51.6	38.5	13.1
	2	460.0	340.0	51.6	26.2	25.4
	3	690.0	110.0	51.6	16.4	35.2
	4	920.0	105.0	51.6	16.2	35.4

NREL: SAN CLEMENTE ISLAND

3 gal/ 75 kW =	0.04
4 gal/ 75 kW =	0.053333
5 gal/ 75 kW =	0.066667
6 gal/ 75 kW =	0.08
7 gal/ 75 kW =	0.093333

	(1) WG	(2) WG	(3) WG	(4) WG
10	1.3	2.8	3.9	4.9
15	3.8	6.8	9.9	13.0
20	7.1	13.4	19.8	26.2
25	9.9	19.1	28.1	35.0
30	11.8	22.8	32.3	34.5
35	12.9	25.0	34.8	34.9
40	13.1	25.4	35.2	35.4

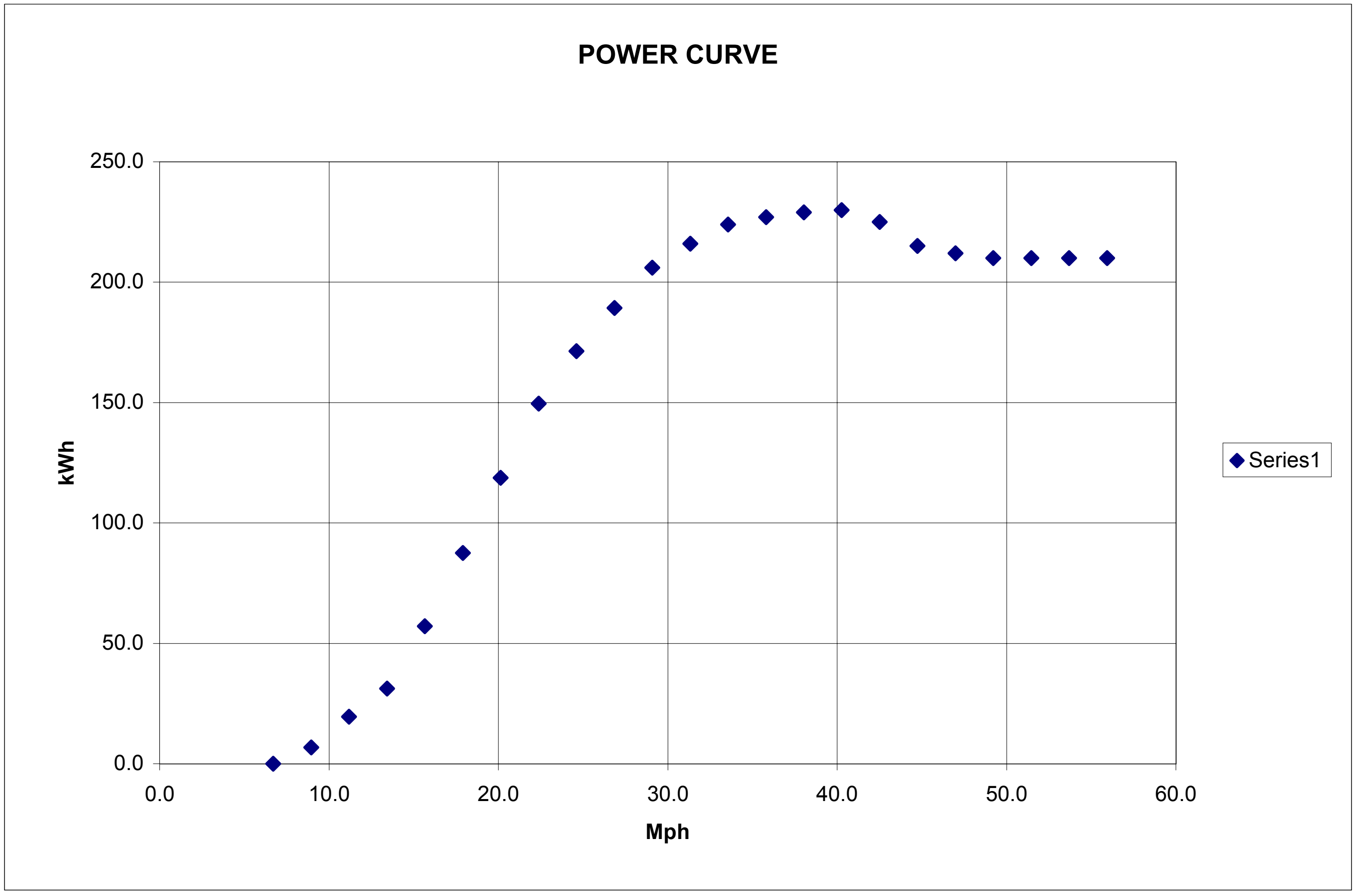


NREL: SAN CLEMENTE ISLAND

Generator Data

POWER CURVE DATA
WIND GENERATOR: MODEL 225kW

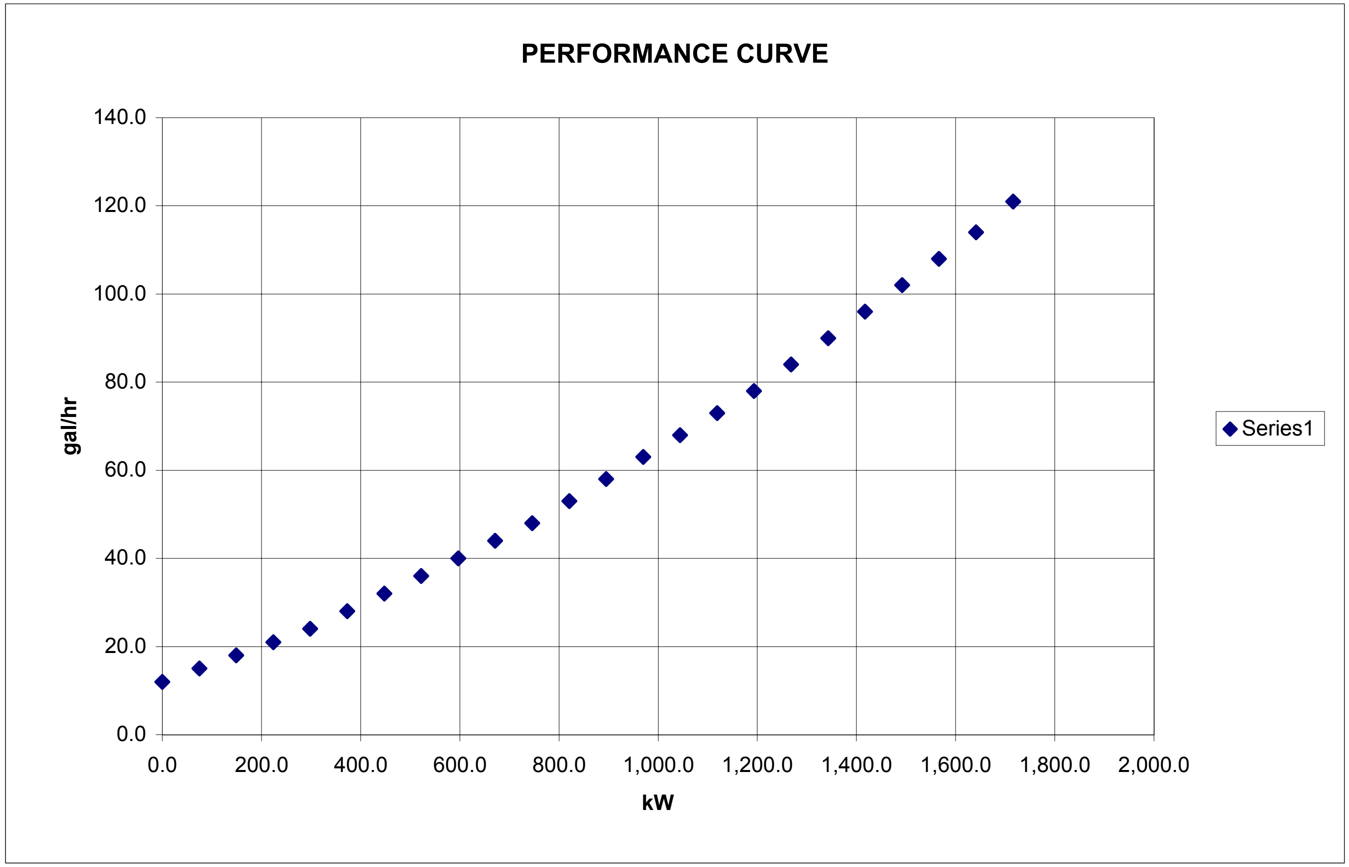
WIND SPEED	WIND SPEED	ELECTRIC POWER
m/s	Mph	kWh
3.0	6.7	0.0
4.0	8.9	6.8
5.0	11.2	19.5
6.0	13.4	31.2
7.0	15.7	57.1
8.0	17.9	87.6
9.0	20.1	118.7
10.0	22.4	149.6
11.0	24.6	171.4
12.0	26.8	189.3
13.0	29.1	206.0
14.0	31.3	216.0
15.0	33.6	224.0
16.0	35.8	227.0
17.0	38.0	229.0
18.0	40.3	230.0
19.0	42.5	225.0
20.0	44.7	215.0
21.0	47.0	212.0
22.0	49.2	210.0
23.0	51.5	210.0
24.0	53.7	210.0
25.0	55.9	210.0
>25	0.0	0.0



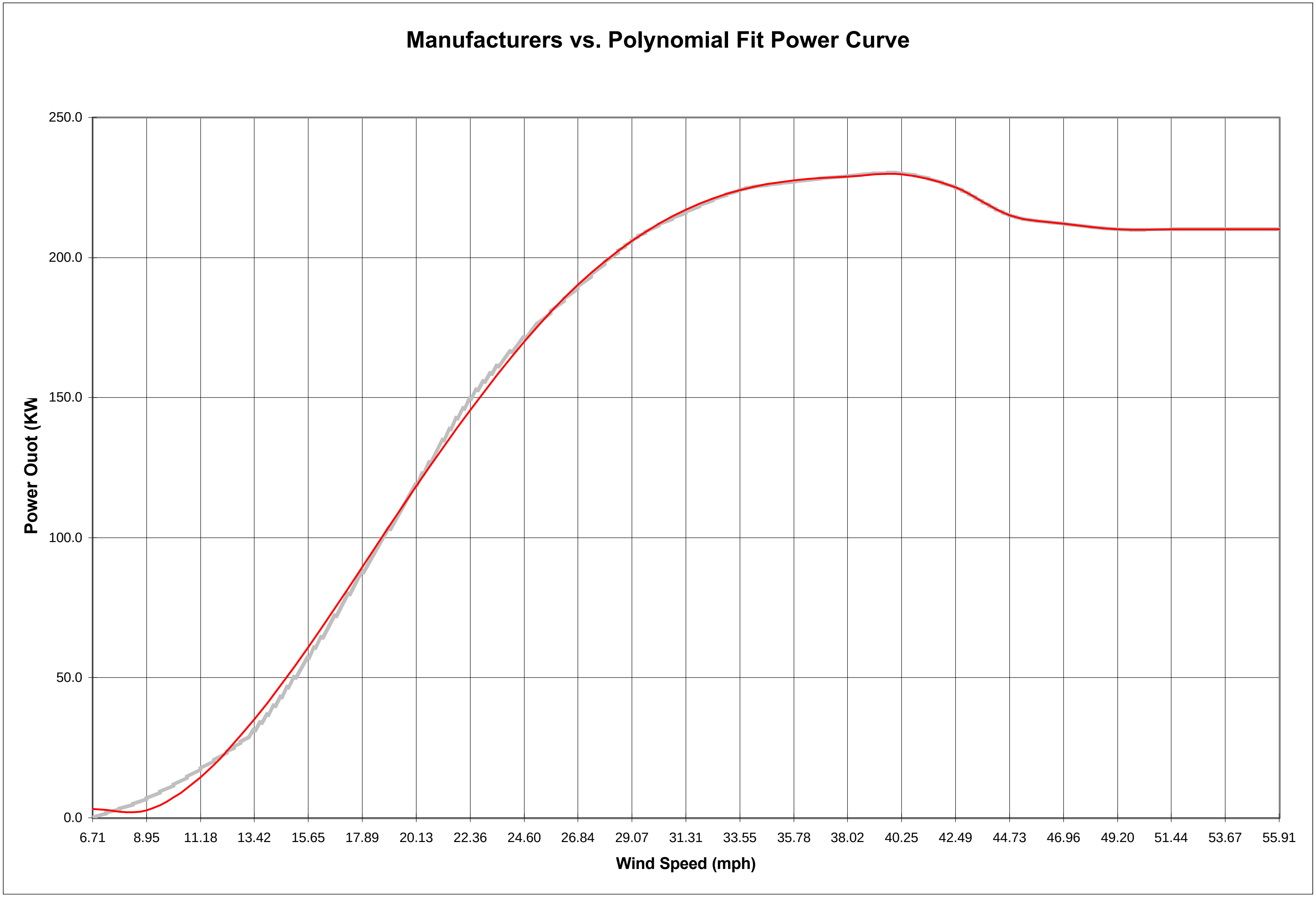
Mph=(m/s)*(2.237)

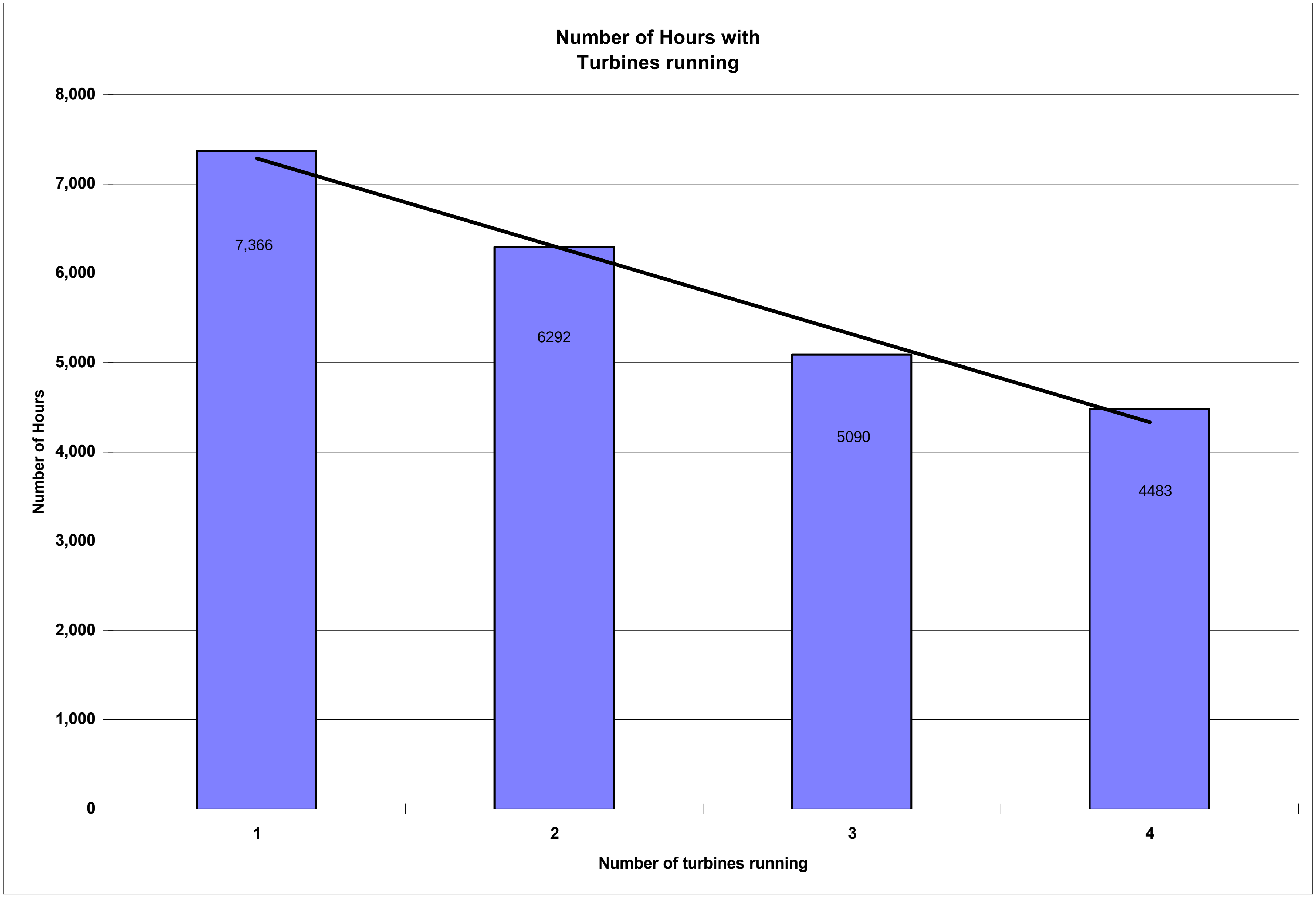
PERFORMANCE CURVE DATA
DETROIT DIESEL GENERATOR: MODEL 16V-149TI SCCC

POWER	POWER	FUEL
bph	kW	gal/hr
0.0	0.0	12.0
100.0	74.6	15.0
200.0	149.2	18.0
300.0	223.8	21.0
400.0	298.4	24.0
500.0	373.0	28.0
600.0	447.6	32.0
700.0	522.2	36.0
800.0	596.8	40.0
900.0	671.4	44.0
1,000.0	746.0	48.0
1,100.0	820.6	53.0
1,200.0	895.2	58.0
1,300.0	969.8	63.0
1,400.0	1,044.4	68.0
1,500.0	1,119.0	73.0
1,600.0	1,193.6	78.0
1,700.0	1,268.2	84.0
1,800.0	1,342.8	90.0
1,900.0	1,417.4	96.0
2,000.0	1,492.0	102.0
2,100.0	1,566.6	108.0
2,200.0	1,641.2	114.0
2,300.0	1,715.8	121.0



kW=bhp*0.746


Manufacturers vs. Polynomial Fit Power Curve
250.0
200.0
150.0
100.0
50.0
0.0
Power Ouot (KW
6.71
8.95
11.18
13.42
15.65
17.89
20.13
22.36
24.60
26.84
29.07
31.31
33.55
35.78
38.02
40.25
42.49
44.73
46.96
49.20
51.44
53.67
55.91
Wind Speed (mph)


Number of Hours with
Turbines running
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Number of Hours
7,366
6292
5090
4483
1
2
3
4
Number of turbines running

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13. ABSTRACT *(Maximum 200 words)*

This report provides an overview of the wind resource, economics and operation of the recently installed wind turbines in conjunction with diesel power for the Naval Air Landing Field (NALF), San Clemente Island (SCI), California Project.

The primary goal of the SCI wind power system is to operate with the existing diesel power plant and provide equivalent or better power quality and system reliability than the existing diesel system. The wind system is also intended to reduce, as far as possible, the use of diesel fuel and the inherent generation of nitrogen-oxide emissions and other pollutants.

The first two NM 225/30 225kW wind turbines were installed and started shake-down operations on February 5, 1998. This report describes the initial operational data gathered from February 1998 through January 1999, as well as the SCI wind resource and initial cost of energy provided by the wind turbines on SCI. In support of this objective, several years of data on the wind resources of San Clemente Island were collected and compared to historical data. The wind resource data were used as input to economic and feasibility studies for a wind-diesel hybrid installation for SCI.

14. SUBJECT TERMS
wind power, wind turbines, wind power and military applications, wind-diesel applications, Federal Energy Management Program

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