COSTA DE COCOS WIND-DIESEL HYBRID SYSTEM

RESULTS OF THREE YEARS OF MONITORING

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ABSTRACT

This paper describes the performance and reliability of the Costa de Cocos wind-diesel hybrid system. The system is located in a remote coastal area in southern Mexico, exposed high temperatures and humidity, salt spray and occasional storm winds. It has experienced problems associated with inverter failure, battery decay and corrosion. Inadequate operation and maintenance practices have also caused some problems. The information collected to date from technical visits and remote data collection is discussed in this paper. The system design and operation is also discussed.

INTRODUCTION

The Costa de Cocos system provides power to a small eco-tourism resort of the same name, located near the town of Xcalak, Quintana Roo, Mexico. It was installed in October 1996 as a pilot project under the Mexico Renewable Energy Program, managed by Sandia National Laboratories (SNL) of Albuquerque, New Mexico. The National Renewable Energy Laboratory (NREL) and the Southwest Technology Development Institute (SWTDI) provided technical support to the project and operated the data acquisition system. The system was designed and installed by Bergey Wind Power Company of Norman, Oklahoma, and features a corrosion-resistant wind turbine package.

SYSTEM DESIGN

A 7.5 kW Bergey Exel wind turbine is installed at the top of a 24-meters tilt-up tower (Fig 1). This unit has a 48-volt stator winding instead of the usual 240-volt winding, which allows a direct connection (without a transformer) to the batteries through the Bergey VCS-10 rectifier/controller. The tower is located about 300 ft from the battery and control room. The battery bank consists of 24 Trojan L-16 batteries (6V, 350 Ah each) connected to form 3 strings of 8 series batteries, for an overall 48 V and 1050 Ah (50.4kWh). In May of 2000, one of the three strings was removed because it had several batteries with severe decay. There are two Trace SW5548 inverters (5.5 kW ac each) stacked together to give 120/240 V ac service. A 25 kW diesel generator connected to the inverters serves as backup and also provides bulk-charge for the batteries. The original design included a 10 kW generator. Recently, a 1 kW PV array was added to the system.

The VCS-10, inverters, overcurrent protection equipment and batteries are installed on a modular galvanized steel structure bolted to the concrete floor (Fig 2). The electronics are fastened to the front of the frame, and the batteries rest on two shelves at the back of the structure. A one-line diagram of the system is shown in Fig. 3.

The VCS-10 regulation set point is 57.5 volts or 2.38 V per cell. There is no temperature compensation for this function. Over-discharge protection and bulk change are provided by the inverters. Both of these functions are temperature-compensated.

Fig 1: Bergey Excel wind turbine at Costa de Cocos, Quintana Roo, Mexico.

Fig 2: View of the system module with electronics in the front side and batteries on the back side.

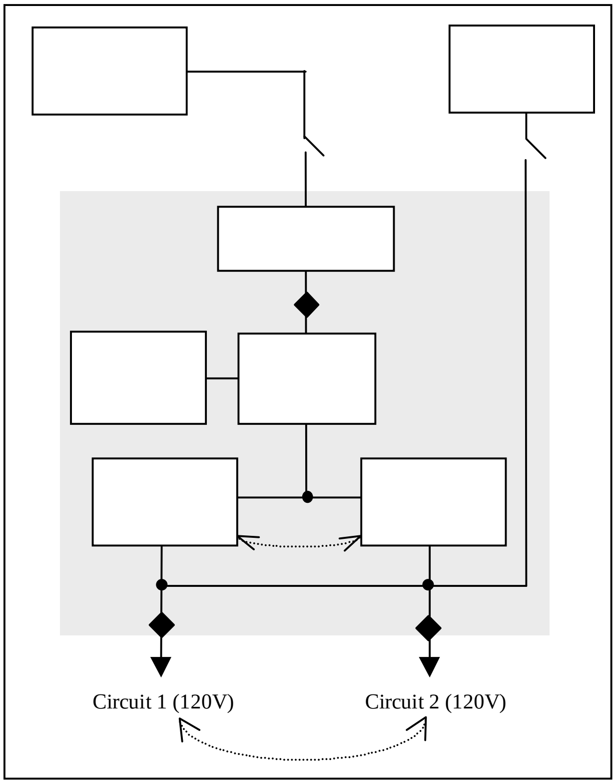

Fig 3. One-line diagram of the system. (The markers "♦" *indicate current and power measurement locations)*

The connected loads include fluorescent lighting and fans totaling about 800 watts, a refrigerator and a reverse osmosis (RO) machine. Power tools are used regularly. The maximum coincident demand is about 1.2 kW served from a 120/240 VAC load center.

DATA ACQUISITION SYSTEM

The data acquisition system (DAS) was designed and installed by SWTDI. It collects electrical and weather data, including wind generator current, battery, current, battery voltage and temperature, inverter dc current, inverter ac power, generator status, ambient temperature and wind velocity. The processing unit is a Campbell 21X datalogger. In April and May 2000, the DAS was upgraded and re-calibrated by NREL. Sensors were added to monitor battery string currents and PV array current

SYSTEM RELIABILITY

The Costa de Cocos system has worked continuously since its installation, but not without problems. The system is located 500 feet from the shoreline and less than 5 miles away from the Xcalack Wind-PV-Diesel hybrid system, where corrosion has affected nearly all major components. In this environment, corrosion is accelerated by continuous exposure to high humidity and salt spray.

There have been frequent inverter trips due to internal overheating and overloads associated with the starting surge of the RO machine. Following the failure of the inverter cooling fans, one of the inverters failed in June 1999 and was shipped to the factory for repair. In January 2000, the inverter was returned to service.

The batteries have suffered a high decay rate. Temperatures in excess of 50 ^{o}C (hourly average) were recorded while charging from the generator. It was also observed that the top-rack batteries operated at higher temperature than the lower-rack batteries, which was initially attributed to the proximity to the cool concrete floor. In April 2000, an entire string (top rack) was disconnected from the bank because 6 of its 8 batteries were bad. This string was physically located immediately behind the inverters. It is very likely that inverter heating contributed to the high operating temperature of this string. The rack design also makes it difficult to maintain the lower rack batteries. These batteries are exposed to acid spilled from the top rack and are difficult to water (Fig. 4).

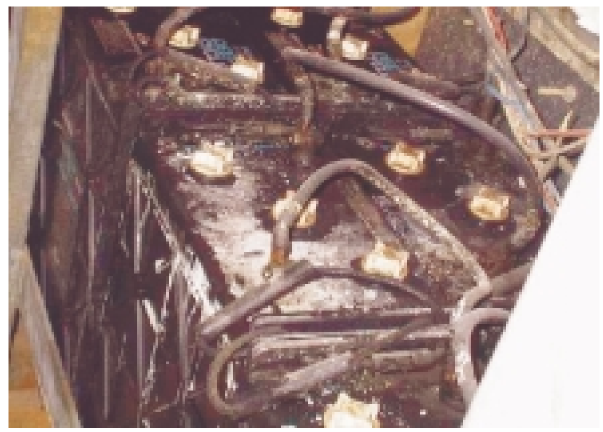

Fig. 4. Lower-rack batteries splattered with acid from the top rack batteries (April, 2000)

Because of the high variability of the wind and the irregular periods of generator operation, battery cycles are not uniform. The data shows that the batteries have remained at or near regulation voltage for periods of up to five days due to continuous high winds. Because there is no automatic generator start, the batteries have been allowed to operate at low state of charge for extended periods of time. During the spring of 1999, the operator began to equalize the batteries once a month. It is likely that little care was taken to re-fill the battery cells with water following equalization, accelerating battery decay.

The wind turbine has been performing satisfactorily. The corrosion package has kept the turbine and tower in good overall condition. However, there is evidence of corrosion attacking the generator can itself and the hub plate. The guy wires exhibit moderate corrosion, especially at the top end. Corrosion is also beginning to affect the furling cable and winch. Turbine noise has been a nuisance for the owner and some patrons. The noise level is not high, but it is relentless. Since late in 1999, the turbine has been producing a low-frequency noise around cut-in wind speed. The source of the noise has not been identified.

The balance-of-system components (switches, fuses, conductors, etc) located in the battery room are in good overall condition. Corrosion has begun to enter the fuse enclosure via battery cables (Fig 5). This will become a problem if not controlled.

Fig. 5. Corrosion entering the dc enclosure at Costa de Cocos (April, 2000)

SYSTEM PERFORMANCE

Table 1 summarizes the energy performance of the system over the period where data was available. The table reports data for the months where the percentage of valid data is at least 70%. Using this criterion, data was unavailable between September 1997 and October 1998, and after December 1999. This is due primarily to telephone communication problems. Where the percent of valid data collected is less than 100%, the data was extrapolated to show an estimated monthly total.

TABLE 1: SYSTEM ENERGY PERFORMANCE DATA[1]

Period	Load (kWh)			Wind (kWh)	Diesel hr. oper	% data
	Total	Circuit 1	Circuit 2			
Feb-97	617.1	412.3	204.8	827.7	43	100
Mar-97	901.6	544.1	357.5	1200.8	33	100
Apr-97	798.9	480.4	318.5	1238.8	32	97
May-97	860.3	586.2	274.1	1090.2	4	100
Jun-97	777.9	554.8	223.2	895.5	116	81
Jul-97	815.0	586.9	228.2	1187.3	1	71
Aug-97	795.8	588.9	206.9	749.7	100	100
Sep-97 to Oct-97	No data available					
Nov-98	801.0	600.8	200.3	1087.0	146	70
Dec-98	955.0	660.2	294.8	713.6	340	100
Jan-99	1097.9	734.0	363.9	1354.4	159	100
Feb-99	1067.3	773.8	293.5	1045.3	151	100
Mar-99	1143.4	854.6	288.8	1366.4	116	100
Apr-99	1233.4	849.0	384.4	1628.0	59	100
May-99	1094.0	693.6	400.4	1555.9	49	100
Jun-99[2]	896.4	763.4	133.0	1329.7	137	99
Jul-99	715.8	715.8	0.0	970.4	95	100
Aug-99	727.3	727.3	0.0	744.0	198	100
Sep-99	436.5	436.5	0.0	763.7	102	96
Oct-99	299.9	299.9	0.0	697.0	20	100
Nov-99	497.1	497.1	0.0	412.4	203	100
Dec-99 to April-00	No data available					

[1] Data projected as necessary to account for missing data
[2] Inverter 2 failed on June 13, 1999.

The average energy supplied through circuits 1 and 2 was 620 and 210 kWh/month, respectively. These totals include generator and inverter output because of the location of the sensors (Fig 3). The peak load for circuit 1 and 2 was about 1.6 kW and 1.0 kW, respectively, and the average load was 0.86 and 0.29 kW, respectively. A load profile for April 1-2, 1999 is shown in Fig. 5. Note that both inverters run continuously and therefore operate at a low efficiency range most of the time, even if a conservative power factor is assumed. The average capacity factors are only 16% and 5%, respectively. Assuming a conservative power factor (70% or higher), it appears that this load could be served by a single inverter and the overall losses could be lowered. The system was designed with two 5.5 kW stacked inverters to supply the 240-volt RO pump motor.

Fig. 7 shows a power curve taken in February 1997 using 1-minute samples. VCS-10 regulation was not a factor because the battery voltage remained below regulation during the test. The peak power is about 7 kW at 14 m/s and the cut-in speed is about 4.2 m/s. The experimental curve is consistent with the manufacturer performance estimates for this machine at sea level in a battery-charging application[1], as shown in Fig 6.

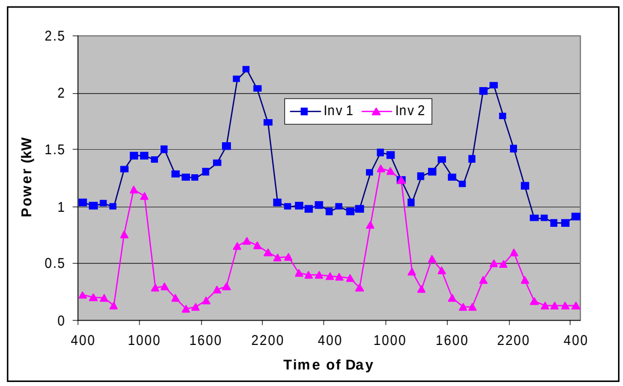

Fig. 6: Typical daily load profile (April 1-2, 1999)

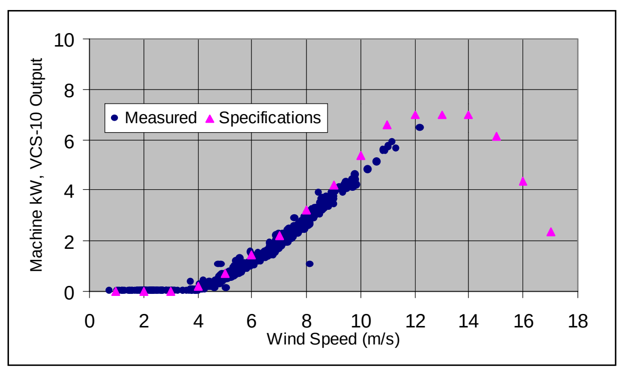

Fig. 7 Bergey Excel measured and expected performance at sea level. 12% turbulence factor

The wind machine has been delivering an average of 1043 kWh/month (43.5 kWh/day) measured at the output of the VCS-10. This corresponds to a capacity factor of about 21% using a 7-kW machine rating. The total monthly energy delivered by the wind machine is plotted against the average wind speed in Fig. 8. An interesting observation is that the data points circled correspond to the earlier months of operation of the system, where the batteries were new.

[1] See http://www.bergey.com/Technical/ExcelR.xls

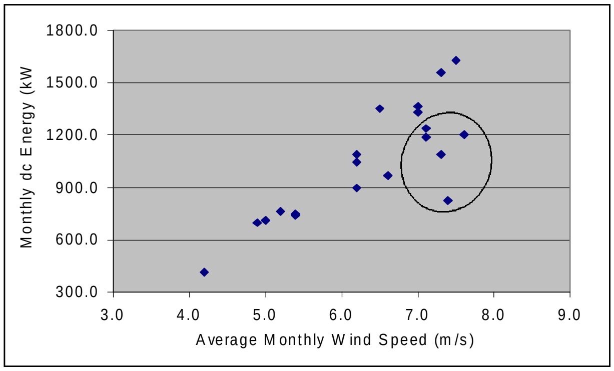

Fig. 8: Monthly dc energy delivered by the wind machine (circled points correspond to first months of system operation)

During nearly every monthly period, the total dc wind energy exceeds the ac energy delivered to the load by about 20%. Because battery roundtrip losses and low inverter efficiency, additional energy from the generator (approximately 100 hours per month) was required. The generator is not fitted with an automatic starter and requires significant manual intervention to operate. Frequent starts are necessary due to the weak battery bank. As shown in Table 1, generator runtime increased from about 45 hours/month in 1997, to about 120 hours/month in 1999. With the addition of the 1-kW PV array in early 2000, generator runtime has decreased significantly.

Table 2 shows battery data. It is worth noting the low roundtrip efficiency of the batteries in the last three months of 1999. This can be attributed in part to higher internal losses in the bad battery string. It is also interesting that the average battery voltage seems to have decreased 3-4 volts since the system began operating.

TABLE 2: BATTERY PERFORMANCE DATA

Period	Avg. bat. voltage (V)	Energy into bat. (kWh)	Energy out of bat (kWh)	Net bat. energy (kWh)	Roundtrip enrg eff (%) [1]
Feb-97	52.7	232.7	125.4	107.3	54
Mar-97	53.8	241.2	161.3	79.9	67
Apr-97	53.2	327.0	199.9	127.1	61
May-97	53.4	254.3	182.2	71.8	72
Jun-97	52.4	370.5	182.7	187.8	49
Jul-97	52.9	271.2	140.5	130.7	52
Aug-97	50.5	336.0	303.7	32.4	90
Sep-97 to Oct-97	No data available				
Nov-98	51.1	474.9	202.1	272.8	43
Dec-98	50.0	309.2	244.5	64.8	79
Jan-99	51.7	525.9	232.5	293.4	44
Feb-99	50.9	328.0	259.3	68.7	79
Mar-99	52.1	424.9	214.9	210.0	51
Apr-99	52.3	488.2	226.8	261.5	46
May-99	52.4	494.7	183.9	310.8	37
Jun-99	51.0	608.8	208.1	400.6	34
Jul-99	49.8	460.1	267.8	192.3	58
Aug-99	49.3	370.2	232.7	137.5	63
Sep-99	50.0	544.3	149.7	394.6	27
Oct-99	49.0	490.1	157.0	333.1	32
Nov-99	48.5	514.9	177.4	337.6	34
Dec-99 to Apr-00	No data available				

[1] Ignoring state of charge at the beginning and end of the period

CONCLUSION

All possible precautions should be taken to control corrosion in humid, coastal environments. This includes the use of stainless-steel hardware, corrosion-resistant enclosures and accessories. Any parts untreated against corrosion will corrode very quickly. Anti-corrosion grease should be applied to all field-installed electrical connections. Corrosion is particularly hard to control in the presence of salt spray or battery acid. Special care should be afforded to grease guy wires and furling mechanism periodically because corrosion can quickly render them unsafe or inoperable. Batteries should be cleaned periodically and all acid spills should be neutralized and cleaned as soon as they occur. The operator should follow a strict preventive maintenance schedule.

It is important to include thermal considerations in the design of battery racks or containers. Even small thermal differences among batteries can contribute to battery decay in the long run. Ideally, the entire battery bank should be placed in a location insulated from sources or sinks of heat such as inverters of bare concrete floors. They should be placed in a plastic container to reduce the risk of acid spills. Any bad batteries should be replaced as soon as possible. This minimizes the chances of other batteries decaying rapidly. A strict maintenance schedule and procedure should be established to take care of batteries. This includes not only adding distilled water, but also monitoring battery temperature and voltage, and keeping them clean. Safety equipment such as goggles and rubber gloves must be used.

When placing wind turbines, noise near dwellings must be considered. Although the noise level is low, it is persistent can become a mayor annoyance.

REFERENCES

Ellis, Abraham, A. Romero and D. Corbus, "Operación del Sistema Híbrido de Costa de Cocos, Quintana Roo, México", ANES 1998.

Newcomb, Charles, Quintana Roo Trip Report, NREL, April 2000

Ellis, Abraham, Xcalak Trip Report, SWTDI, October 1998

SWTDI, Costa de Cocos Monthly Performance Summaries, February 1997 - November, 1999.