Hawai'i Energy and Environmental Technologies (HEET) Initiative

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TASK 4 ALTERNATIVE ENERGY SYSTEMS 4.5 Energy Test Platforms: Crissy Field Center Wind Power Study: Final Report

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Deliverable 7 Final Report

Crissy Field Center Wind Power Study

HNEI Subcontract, Prime Award No. N00014-10-1-0310

Golden Gate National Parks Conservancy 9/21/2015

Background

Per the terms of the project contract between the Golden Gate National Parks Conservancy and the Hawaii Natural Energy Institute, dated October 14, 2011, and as outlined in the Statement of Work, the Golden Gate National Parks Conservancy (Parks Conservancy) will plan, permit, install and operate up to five wind energy systems at the Crissy Field Center (CFC), an existing modular test platform manufactured by Project Frog. The Parks Conservancy will develop a Data Acquisition System (DAS) that will record wind speed, wind direction, and power generation for each wind energy system. Data from the DAS shall be made available to HNEI sufficient for industry standard analysis.

Performance of the turbines on the site will be monitored for approximately five years, with full access by HNEI to monitoring equipment and data. Project FROG will assist the Conservancy with integrating the wind energy data into a monitoring system that will track overall building performance – the system will also include a simple dashboard interface for use by the Center's education programs.

Deliverable 7: Final Report

The Deliverables and Payment Schedule in the Contract Statement of Work stipulates that for report 7: "Report shall include observations and findings on the performance of the wind turbine systems and data acquisition systems."

Crissy Field Center Wind Power Study

Data Analysis and Observations

Project Life Performance

The five turbines were installed in July of 2012. Simultaneous wind and turbine output was recorded from October 5, 2012 forward. Figure 1 illustrates power generated over the project life of each turbine. The two Windspires (T14 and T18) generated energy continuously from project beginning through Dec 31, 2014, when one Windspire tower failed and the other was taken out of commission as a precaution. The Venco turbines operated up to July 31, 2014, when the turbines experienced a mechanical failure Each of the Venco turbines experienced a series of bearing seizures which took them out of commission for 3-5 months. They were repaired but failed and were taken offline July 30, 2014. The Tangarie turbine experienced blade failure late June 2013 and was decommissioned shortly thereafter.



Figure 1: Daily average power output over turbine life

With 816 days of minute-level data, actual performance was compared to expected performance for both wind resource and turbine generation. Figure 2 presents key findings from the data.

Annual Generation Summary (Period of Performance October 5, 2012 to December 31, 2014)								Rated Capacity Factor	
Manufacturer	Rated Power (kW)	Run Days	Observed Average Wind Speed (m/s)	2012 to 2014 Total Output (kWh)	2012-2014 Average Daily Output (kWh/day)	Projected Ave. Daily Output at Observed Wind Speeds per Manuf. Spec. ¹ (kWh/day)	Capacity Realization Rate at Observed Wind Speeds (%)	Rated Capacity (kW)	Capacity Factor (%)
Windspire 1 ²	1.2 @ 10.7 m/s	816	3.6	1,196	1.47	0.72	204%	1.20	5.09%
Windspire 2 ²	1.2 @ 10.7 m/s	816	3.6	1,058	1.30	0.72	180%	1.20	4.50%
Venco 1 ³	1.0 @ 12.0m/s	556	3.6	280	0.50	0.72	70%	1.00	1.43%
Venco 2 ³	1.0 @ 12.0 m/s	514	3.6	194	0.38	0.72	52%	1.00	0.99%
Tangarie ⁴	2.0 (speed not specified)	268	3.6	107	0.40	NA	NA	2.00	0.27%

¹ Estimate of manufacturer's output at observed average wind speed of 3.6 m/s.
³ Venco units taken offline July 2014 due to materials failure

 $^2\,$ Windspire units taken offline December 31, 2014 due to materials failure $^4\,$ Tangarie unit taken offline July 1,2013 due to materials failure

Figure 2: Summary of key performance findings

Finding 1: Both Windspire turbines operated from October 6, 2012 through December 31, 2014, or 816 days. The Venco 1 and 2 turbines had intermittent operating issues described in other sections of this report operating for a total of 556 and 514 days respectively. The Tangarie turbine operated for only 268 days, having failed by June 30, 2013

Finding 2: The observed average windspeed was lower than predicted from the wind study commissioned by the Parks Conservancy. The predicted average wind speed was 4.7 m/s (10.5 mph) using the data from the Anita Rock wind site. The observed average wind speed was 3.6 m/s, 77% of the projected wind speed.

Finding 3: From an observed wind velocity profile created on a minute to minute basis, the projected turbine outputs were forecasted based on the manufacturers power curves. For the Windspire turbines, the total actual generated energy was nearly twice as high as would have been forecast at the observed wind regime. (Note: Power curves were not available for the Tangarie turbine.) The Windspire 1 and 2 generated 204% and 180% respectively, of the energy expected at observed wind regime. The Venco 1 and 2 turbines generated 70% and 52% of the expected energy, respectively. The energy expected from the Tangarie could not be determined since there was no manufacturer's power curve available.

Finding 4: While Finding 3 was a comparison of actual energy to the power curve, Finding 4 highlights the capacity factor at rated conditions. The Windspire rated capacity is 1200 Watts at a windspeed of 10.7 m/s. The Venco rated capacity is 1000 Watts at windspeed of 12.0 m/s. The Tangarie capacity is rated at 2000 W and no wind speed specification.

The Capacity Factor is the observed amount of energy produced relative to the amount that would have been generated if the turbine ran at full capacity over the specified duration. For this analysis, the duration is the 816 days of measured data from October 5, 2012 through December 31, 2014.

The Windspire capacity factors were 5.09% and 4.50%. The Venco capacity factors were 1.43% and 0.99%. The Tangarie capacity factor could not be determined due to lack of manufacturer data.

Other Findings and Observations

There is no robust relationship between average wind speed and the power output of any of the VAWTs at Crissy field on a minute-to-minute basis, as can be seen readily by examining the scatterplots below.



Figure 3 Power platted against wind indicating weak relationship

The poor relationship in the data set between wind speed and power output seems to be due to the fact that the wind turbines are sampled instantaneously every 60 seconds, whereas the wind data is an average over 60 seconds. As the output from the VAWTs varies significantly within a one minute time period, the instantaneous "snapshots" recorded every 60 seconds are not representative of the power output over the rest of the period. This idea is supported by the fact that there is significantly less scatter in the relationship between wind speed and VAWT output if one only considers "steady wind", defined at a standard deviation of wind speed over one minute of less than 1 mph (below).



Figure 4 Scatterplot of power and wind for Windspire 1

Effectively, the 60 second snapshots are a random sampling of the underlying probability distribution of turbine power output. In order for these random samples to be representative of the real output from the turbines, they must be averaged over a long period of time. A straightforward way to accomplish this is to examine daily averages, as can be seen in the figure below, which displays the daily averages of wind speed and power output for the various VAWTs for the year 2013. Note that we have excluded the Tangerie VAWT from the remainder of the analysis due to the short period it was operational.



Figure 5 Power plotted against Daily average

As can be seen, the relationship between wind speed and VAWT power output are much more robust on a day to day basis. However, the daily average of the wind speed rarely exceeds 8 mph, which allows for examining only the lower end of the power curves. A daily average wind profile (below) shows that at Crissy field the wind peaks in the afternoon, so we repeat the analysis using only data from between 12 - 9 pm.



Figure 6 average daily wind profile



Figure 7 Afternoon average power output

Better representing actual short term turbine performance, the resulting afternoon averages show a similar relationship between wind speed and power output for the Windspire and Venco VAWTs at lower wind speeds, while revealing more of the relationship at higher wind speeds. Overall, it is apparent that the Windspire turbines outperform Venco turbines by a large margin. This is true both for total power output and power output relative to the rated power. The plot below shows the actual afternoon averages of VAWT power output versus what would be expected given the published power curves for the respective VAWTs. Simple linear estimates of the actual versus expected power output indicate that the Windspire turbines perform at approximately 45% of their rated value at Crissy field,

while the Venco turbines perform and approximately 27% (see figure 8).



Figure 8 Actual power output compared to expected

The Wind Regime

The wind regime at the Crissy Field site is quite different than when measured from an unobstructed reference wind site such as Anita Rock. Trees and buildings surrounding a site create an "urban wind" effect that reflects diminished velocity and power of the wind, while creating turbulence that may also impact the ability to translate wind into power across a turbine blade.

The annual average wind speed measured at Crissy Field is shown in Fig. 9, showing observed annual averages ranging from 3.73 to 3.98 m/s for the two years with complete data. Data for 2012 was only available from October 5-December 31. The 4 year average at Anita Rock is 4.28 m/s, with gusts to 5.25 m/s.



Figure 9 Average annual wind speed measured at Crissy Field

Much of the observed wind is less than 8.0 m/2, with the velocity ranging from 1.0 to 5.0 m/s much of the time.



Figure 10 Count of Average Wind Speed for each Average Wind Speed bin



Figure 11 Monthly variation of wind speed

Wind Direction

Wind is predominantly WSW, with a secondary north component as illustrated in the wind rose, Fig. 12. Figure 13 adds a time dimension by indicating percent of total wind hours for each 45 degree quadrant.

A third party, WeatherFlow, provided 2 years of data collected from Anita Rock as indicated in Figure 14. Visual inspection shows prevailing direction of approx. 240 degrees. The wind data collected on site, and at Anita Rock conflicts with the wind rose provided to the Conservancy in 2010, suggesting further investigation to determine which data source accounted properly for the magnetic declination for this region. A misapplication of the magnetic declination correction factor can make from 15 to 30 degree difference in reported wind direction.



Figure 12 Wind rose for all observed data points



Figure 13 Wind direction in 45 degree bins. Percent of total measured wind hours



Figure 14: Anita Rock wind direction data sourced from Weatherflow



Figure 15 Wind Rose From Crissy Field Wind Prospecting Study