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Crissy Field Center Wind Power Study Phase II: Commissioning of the Wind Turbines and Data Acquisition System

Task 7

Prepared For Hawaii Natural Energy Institute

Prepared By Golden Gate National Parks Conservancy

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Crissy Field Center Wind Power Study Phase II, Report 3: Commissioning of the Wind Turbines and Data Acquisition System

Prime Award No. N00014-13-1-0463, HNEI Subaward No. MA160014

Background

Per the terms of the project contract between the Golden Gate National Parks Conservancy and the Hawaii Natural Energy Institute, dated May 6, 2016,

and as outlined in the Statement of Work, The Golden Gate National Parks Conservancy (GGNPC) will plan, permit, install and operate four new vertical axis wind energy systems at the Crissy Field Center (CFC), an existing modular test platform manufactured by Project Frog. The GGNPC will modify existing infrastructure and the Data Acquisition System (DAS) from the prior wind study project to 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.

Report 3: Commissioning of the Wind Turbines and Data Acquisition System

As outlined in the Deliverables and Payment Schedule, Report 3 "shall include documentation of functional operation and commissioning of the turbine systems. Report shall include documented evidence of installation and commissioning of the turbines and data acquisition system including photos and statements of commissioning by SUBRECIPIENT, and HNEI verification of receipt and acceptance of data and data format."

All of the work associated with the installation of the new wind turbines for phase II, including tower retrofitting, electrical component and conductor installation was substantially complete by April 19, 2017. (See report 2.2)

Prior to releasing the turbines and associated equipment to Loisos & Ubbelohde for the DAS equipment installation, Luminalt, the installation contractor, performed testing to verify that the turbines spun, braked and operated properly. Luminalt summarized the commissioning process as follows:

- 1. Commission turbine inverter systems per manufacturer instructions. This included programming the correct wind curves into the UGE inverters. The Omniflow turbines were sent with correct factory programming.
- 2. Allow turbines to free spin (with no inverter load) and verify that they spin up in light wind
- 3. For UGE, move operational switch located on automatic safety brake to free spin, normal operation, and brake modes and verify that turbines operate as expected. We also verified on a very windy day that the maximum rotational speed was achieved and saw both the Southern and Northern units enter into automatic brake mode, and then back to normal operation after the countdown period
- 4. For Omniflow, we manually operated the brake switch out by the turbine towers and verified that they stopped spinning

After the systems were tested and verified, Luminalt released the fully operational turbine systems to Loisos & Ubbelohde to perform the DAS installation and commissioning.

The report below, produced by Loisos & Ubbelohde, documents the commissioning process for the DAS. The report includes sections on data collection, challenges with power monitoring, data transfer and verification, and the updating of the system dashboard interface. Work associated with the DAS commissioning was complete by May 31, 2017, at which point all systems were functioning and operational.

LOISOS + UBBELOHDE

ARCHITECTURE . ENERGY

1917 Clement Ave Building 10А • Alameda, CA 94501-1315 510 521 3800 РНОЛЕ • 510 521 3820 FAX

MEMORANDUM

DATE	21 June, 2017
то	Tom Odgers Golden Gate National Parks Conservancy
	Jim Maskrey Hawaii Natural Energy Institute
FROM	Nathan Brown, Associate
RE	Crissy Monitoring Software Update and Commissioning Report

This memo describes the completed software updates and commissioning of the monitoring and dashboard system. This report constitutes the final deliverable for Task 3 from the Consulting Services Agreement dated June 15, 2016. This Task included work on both monitoring systems: the high frequency monitoring system is collecting data at a 1-second interval, and the existing whole-building monitoring system continues to collect data at the 10-minute interval. The system is described in detail in the Installation Report (see memo dated May 24, 2017).

EXECUTIVE SUMMARY

The high frequency monitoring system is functional, and data are being automatically transferred from site to the FTP server at the Hawaii Natural Energy Institute (HNEI). Data from the new monitoring equipment include power production for each of the four new wind turbines (two Omniflow turbines, and two UGE turbines) and wind speed and direction at each of the turbine towers. These data have been reviewed; they vary within expected limits and exhibit expected patterns of variation.

The Omniflow turbines have been successfully integrated into the existing monitoring and dashboard system. This included configuring the existing system to be consistent with the new equipment as well as updating the dashboard to reflect the new turbine configuration.

The UGE turbines have exhibited unexpected behavior that required an adjustment to the monitoring approach. In particular, we find that the existing equipment is not able to monitor the power produced by these turbines with consistent accuracy. However, we have identified a calculation that will allow power production to be estimated with accuracy that may be sufficient for the dashboard. This calculation will be implemented after this report is issued.

Detailed study of the UGE turbine performance also indicated variation in performance between the north and south UGE units: the UGE north turbine exhibits a high frequency pattern of power production.

HIGH FREQUENCY MONITORING SYSTEM

Data Collection

A dedicated controller collects data at a 1 second interval. The data collection is initiated by a series of commands to the sensors via serial communications. This series of commands includes 5 distinct requests for data (one request is for all wind sensor data, and the other 4 requests are for individual power measurements). These requests are sent out sequentially, allowing time for the device to respond with data before the bus is used for the next request. All commands are sent and data received within the first 700 milliseconds of the 1-second interval.

The following table shows the sensors that are monitored at a 1 second interval. The deviceID and sensorID numbers are used in the data files to differentiate data points. Please note that we installed the monitoring equipment such that "negative" power refers to power entering the panel (ie, power produced), while "positive" power refers to power leaving the panel (ie, power consumed).

	deviceID	sensorID	units
Wind speed, tower 1 (north)	1	1	m/s
Wind direction, tower 1 (north)	1	3	deg
Wind speed, tower 2	1	5	m/s
Wind direction, tower 2	1	7	deg
Wind speed, tower 3	1	9	m/s
Wind direction, tower 3	1	11	deg
Wind speed, tower 4 (south)	1	13	m/s
Wind direction, tower 4 (south)	1	15	deg
Power, tower 1 (north) positive	10	6002	W
Power, tower 2 positive	11	6002	W
Power, tower 3 positive	12	6002	W
Power, tower 4 (south) positive	13	6002	W
Power, tower 1 (north) negative	10	7002	W
Power, tower 2 negative	11	7002	W
Power, tower 3 negative	12	7002	W
Power, tower 4 (south) negative	13	7002	W

Converted data files (located in the "data_final" directory) contain rows as follows, where values include integer values as well as converted 32-bit floating point values:

```
<timestamp>,<deviceID>,<sensorID>,<value>
```

Timestamp is given as 'YYYY/MM/DD hh:mm:ss'. Data files are saved with measured data at a 1-hour interval; the identifier will be approximately the first timestamp measured, as a Unix timestamp. For instance, the head and tail of file "1495555161_data" is as follows (this is an older file showing 4002 registers used for power):

2017/05/23 15:59:22,10,4002,9
2017/05/23 15:59:22,1,1,3.64700007439
2017/05/23 15:59:22,1,3,261.68762207
2017/05/23 15:59:22,1,5,2.84700012207
2017/05/23 15:59:22,1,7,277.566955566
2017/05/23 15:59:22,1,9,4.4470000267
2017/05/23 15:59:22,1,11,251.398193359
2017/05/23 15:59:22,1,13,4.4470000267
2017/05/23 15:59:22,1,15,265.150390625
2017/05/23 15:59:22,1,17,0.0
2017/05/23 15:59:22,11,4002,10
2017/05/23 15:59:22,12,4002,4
2017/05/23 15:59:22,13,4002,11
2017/05/23 15:59:23,10,4002,9

· ·
· ·
2017/05/23 16:59:21,11,4002,27
2017/05/23 16:59:21.12.4002.18
2017/05/23 16:59:21.13.4002.11

Raw data files containing unconverted floating point values

(<value>=<word1>,<word2>) and raw Unix timestamps are also saved as backup (these are located in the "data_raw" directory). Note that unless noted, all timestamps are UTC, not local time.

UGE Power Monitoring

In the process of commissioning the UGE power monitoring, we discovered an unexpected and unusual issue. The UGE inverters are connected to the electrical panel using 2-pole breakers. We discovered that during lower levels (<280W) of power output, the direction of current in each wire is opposite, and the total power produced or used is the difference between the readings. This required a change to explicitly monitor net positive power and net negative power (as is reflected in the registers described above). The former method measured total power – or the sum of the absolute values for power on each phase. This showed a near constant 300 W of power produced, even though the totals were much lower. For example, we performed a test on site where the UGE North turbine was switched from power production to "free spin" mode, and then back to power production mode (see graph on following page). This shows the variation in power logged in each wire (L2 and L3), in the calculated Net Power, and in the calculated Total (absolute) Power. This graph further demonstrates why Net Power needs to be calculated rather than using the Total Power.

Luminalt and Loisos + Ubbelohde researched the issue and discussed these observations with Ginlong, the turbine manufacturer, and with Dent Instruments, the manufacturer of the Powerscout meters. The team identified low power factors as a likely cause of these observations, as described in more detail in this document, posted by Continental Control Systems, another power meter manufacturer:

https://ctlsys.com/support/inverter-power-factor/

While this issue presents further monitoring challenges for the dashboard data collection (see below), for purposes of the high frequency monitoring, it confirms that our monitoring of net power will accurately capture total power production or use at any given moment in time.





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Data Transfer

Data files are first saved locally on the controller. A cloud-based server was developed to retrieve, convert, and transfer data files. This server is implemented as a Flask server running on Heroku. Since FTP access to the controller and HNEI servers required whitelisting of the server IP address, a service was added to the Heroku server to provide a static IP address via a proxy server. The Heroku server and the proxy server incur a monthly cost, which we will include with our monthly maintenance budget. The controller was programmed to save data hourly and to contact the server after a new data file has been saved. The server then retrieves any datafiles from the controller, converts the data to engineering units as described above, transfers both the raw and converted data to the UHM HNEI FTP server located at crissy.soest.hawaii.edu, and finally deletes the original files from the controller. The data transfer server has been deployed, and the data transfer process is operational.

Data Check

A data file (the converted data file 1495555161_data.csv) was downloaded and checked for potential errors. Wind speed, wind direction, and power were plotted for each wind turbine, using a 2-second average to enhance readability. At the time of this initial check, the UGE wind turbines had not yet been fully commissioned. A second data file (1495669392_data.csv) was downloaded to examine UGE data. The data check of each of these files showed data range and variation consistent with expectations (see graphs below). In particular, we note:

- Wind speed and direction vary, but patterns are consistent across sensors.
- Power monitoring of the Omniflow turbines shows increases that seem to correspond to increasing PV output.
- Wind speed resolution is somewhat coarse this is unavoidable since the execution interval of data collection is so small. The sensor uses a pulse signal with each full rotation of the anemometer, so there is no way to measure a fraction of a rotation.
- UGE North turbine and wind data for wind speed and power generated show very similar patterns of variation.
- UGE North turbine shows high frequency variation in performance that is different from the UGE South turbine – see detailed discussion in below.



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EXISTING MONITORING SYSTEM UPDATES

The existing system needed to be reconfigured to properly record and display data from the new wind turbines. This included changes to the data collection system as well as the dashboard interface.

Data Collection

The system was updated to log data from each of the four new wind turbines. This included updating the configuration to accept inputs corresponding to the wiring of each new turbine, review of system setting to ensure compatibility with new turbines, and verification that data were being collected and processed as expected.

UGE Power Issue

The issue described above regarding the need for logging of Net Power is an issue for the existing monitoring system, because the existing Powerscout 18 is not capable of logging Net Power. It logs Total Power, or the sum of power from each phase. As a result, it will over-estimate power production any time Net Power production is less than around 280W.

We have identified three potential solutions to monitor the power production of these UGE units:

- The Powerscout 18 unit can be replaced with a Powerscout 24 unit that is capable of sensing the direction of current flow and can track Net Power. This will ordering and configuring the new equipment, installing the equipment on site, and integration of the equipment with the existing system.
- 2. Due to the observed behavior of the current flowing from the inverter, it appears that a calculation could be applied to estimate power produced by the UGE turbines. In the graph above, note that L3 power is always positive, and that L2 power switches to positive when L3 power is above approximately 280W (although this limit is inconsistent). In order to infer the sign of L2 power, we can test to see if L3 power is above or below 280W, and assign a negative number to L2 if L3 is below 280W.
- 3. The document provided by Continential Control Systems (see link above) provides a method for calculating total power by monitoing apparent power and power factor for a single phase. This calculation could be performed for data from a single CT using the Powerscout 18, thus allowing us to calculate corrected total power from one CT.

We further investigated the second and third solutions by recording detailed data for each UGE turbine using the Powerscout 24 to both simulate data collected by the Powerscout 18 and to measure net power. We were thus able to test each potential calculation method. We found that calculating total power using the 280W threshold was slightly more accurate than calculating the total using data from a single CT, and it was also easier. Based on our test of using the 280W threshold, we found this would produce accurate results for small or large power values, and an occasional error up to \pm 50% when total power is around 280W. We found that this error was larger for the UGE North turbine, which exhibits a high frequency pattern of variation in its output, than for the UGE South turbine. See figures below for the percent error vs measured power for each turbine. We also plotted the measured and calculated values over time, and we note that when taken as a whole, the calculated values tend to show a similar overall pattern (ie, when measured power is high, calculated power tends to be high as well).

This may be a "good enough" solution for the dashboard, since this interface is meant to indicate performance rather than precisely track performance. Dashboard data collection for UGE turbine power production was suspended when we identified this as an issue, pending a solution. Given cost considerations and the general purposes of the dashboard, our recommended solution is to apply calculation method 2, above. This solution was implemented on June 16, 2017, as reflected in the data shown in the dashboard (see second image on Page 14 below).

Note that the high-frequency data collection described above is not subject to this issue (since it uses a Powerscout 24), and so precise performance data will be available as needed.





Dashboard Interface

The dashboard interface was updated to include images and graphs to match the new installation. This involved reducing the number of graphs shown in the "per turbine" page and updating the legend to show images of the new turbines. While the intent was to represent the solar power and wind power produced by the Omniflow turbines separately, these values could not be disaggregated as planned (see memo titled 161025_omniflow_monitoring for further discussion). See screen shot of updated interface below.



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