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Crissy Field Center Wind Power Study Phase II: Report on Recommendations for Wind Turbine Systems and Data Acquisition System

Task 7

Prepared For
Hawaii Natural Energy Institute

Prepared By
Golden Gate National Parks Conservancy

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HNEI
Hawaiʻi Natural Energy Institute
University of Hawaiʻi at Mānoa

Deliverable 1: Report on Recommendations for Wind Turbine Systems and Data Acquisition System

Crissy Field Center Wind Power Study Phase II

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

Golden Gate National Parks Conservancy May 20, 2018

Background

Crissy Field Center Wind Power Study, Phase I

In July 2012 contractors completed the installation of five vertical axis wind turbines (VAWT) and a data acquisition system (DAS) at the Crissy Field Center, in the Presidio of San Francisco. The turbines and DAS were components of Phase I of the Crissy Field Wind Power Study, a project conducted by the Golden Gate National Parks Conservancy with funding from the "Hawaii Energy and Environmental Technologies" (HEET 2009) project, N00014-10-0310. Phase I was completed in September 2015.

The purpose of Phase I was to evaluate the performance of vertical axis wind turbines in an urban environment. The criteria for evaluation of this relatively new technology included:

> -Functionality of each of the turbine models, including power generation relative to wind speed and wind direction shifts. These assessments were developed using data acquired from the DAS and monitoring systems.
> -The effect of the turbines on wildlife (particularly birds and bats). This was achieved through a wildlife impact study conducted by the GGNPC/NPS during the first year of the turbine operation.
> -Noise generation, as observed by staff during VAWT operation.

The study found a wide range of performance between the three types of VAWT. For details on the performance of the individual turbines, including information on power production and maintenance requirements please reference the relevant Phase I reports, located here: https://parksconservancy.box.com/s/iq2f10kaicqv6wu90bsp

The DAS system functioned as designed. Analysis of the data acquired by the DAS, however, yielded a flaw in the design of the data collection protocol which resulted in a "poor relationship" between the data sets for wind speed and power output. This flaw was attributed to the comparison of instantaneous and averaged data and resulted in imprecise correlations between wind speed and power generation. For more information on the performance of the phase I DAS system, please reference the Phase I report No. 7, located here: https://parksconservancy.box.com/s/n9d3di8zovso6ar3yh4uwfhe99rpzt55

The wildlife impact study, conducted by GGNPC staff under direction of NPS, was conducted between July 2012 and July 2013. Continuous observation during this one year period resulted in the observation of two bird kills. For more information please reference the documentation on the Wildlife Impact Study, located here: https://parksconservancy.box.com/s/fbwqyllhweit5pnppm4lsowotc1gm751

Noise: The project administrators and staff at the Crissy Field Center verified that when operating normally, none of the wind turbines produced noise that could be detected above the ambient noise levels, regardless of wind speed.

Besides the data gathered above, the turbines were the most visible renewable energy feature installed at the site, and effectively promoted the environmental mission of the Center, as well as the sustainability goals of the Park. They also contributed to the Center's attainment of LEED Platinum certification and were engaging elements in the Center's educational curriculum.

Phase II

Phase II marks the continued evaluation of VAWT technologies, with the purchase and installation of four new turbines from two different manufacturers. Monitoring of the new turbines' performance and wind conditions will be achieved using a DAS with an improved design, based on the lessons learned from phase I.

Objectives

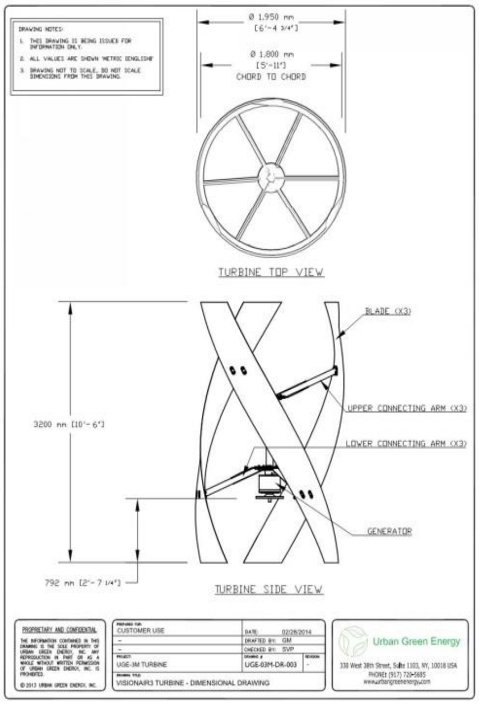
Per the project SOW:
"The objective of the second phase of research is to evaluate and test selected wind turbine technologies to determine the relative effectiveness of differing turbine design technologies; the impact of urban wind conditions (environment-induced turbulence) relative to idealized (laminar) wind conditions under which turbines are tested and rated; and integration with the test platform systems toward the achievement of energy neutrality and/or net positive energy within the test site."

The Crissy Field site provides an ideal location to conduct wind technology research, as the site is subject to urban wind conditions and is immediately adjacent to the unobstructed area of the San Francisco Bay:

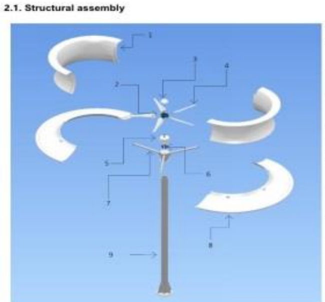
"The wind regime at the Crissy Field site is quite different than when measured from an unobstructed reference wind site such as Anita Rock. Trees and buildings surrounding a site create an "urban wind" effect that reflects diminished velocity and power of the wind, while creating turbulence that may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

Turbine Specifications

The two turbines selected for Phase II of the project are the UGE Vision Aire 3 and the Omniflow OM 12.



UGE Vision Aire



Omniflow

2.1. Structural assembly

Item no.	Description
1	Omnidirectional diffuser
2	Hub
3	Spinner
4	Rotor blades
5	Generator
6	Anti-shock absorbers
7	Supporting Metal Frame (SMF)
8	Solar wing
9	Mast

3. MAIN COMPONENTS

A list of the complete setup is detailed below, including electrical components. A complete parts list of OM12 can be found in Appendix A.

Description	Quantity
Solar wing (2 parts)	1
Omnidirectional diffuser (2 parts)	1
Supporting metal frame (SMF)	1
Union board generator-SMF	1
Anti-shock absorber	6
Generator	1
Blade	5
Hub	1
Spinner	1
Charge controller	1
Inverter (grid tie/battery charging)	1
Brake resistor	1
Manual brake switch	1
Backup battery	2

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Omniflow OM 12

Turbine Installation Design

The design team for phase II was tasked with making use of the existing infrastructure from phase I to the greatest extent possible. Existing footings, conduit and conductors were re-used, and in the case of the Omniflow units, the towers from the Phase I Venco units were retrofitted to accept the new turbines.

UGE Footing Adaptation:

The UGE units, together with new towers, were to be installed on existing Windspire footings. The stud pattern in the existing footings was evaluated by the engineering team, which decided to supplement the existing attachments with new 1-¼" epoxy embedded anchor rods. See figure 1 below:

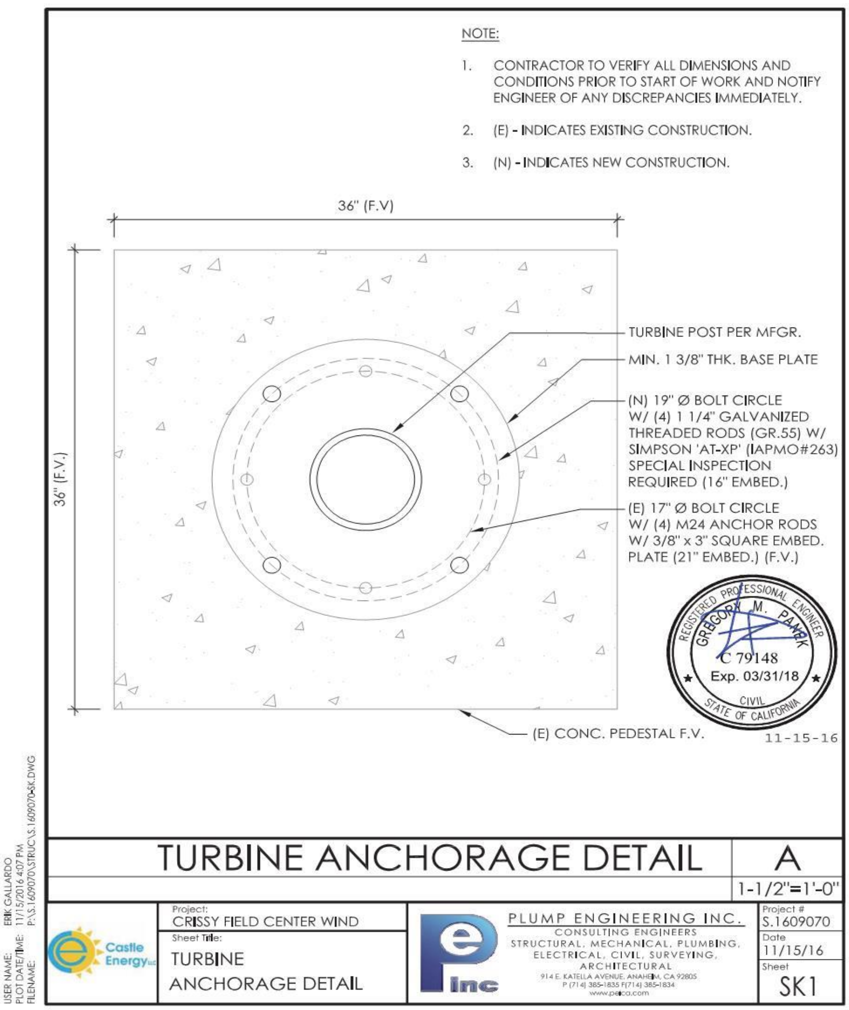
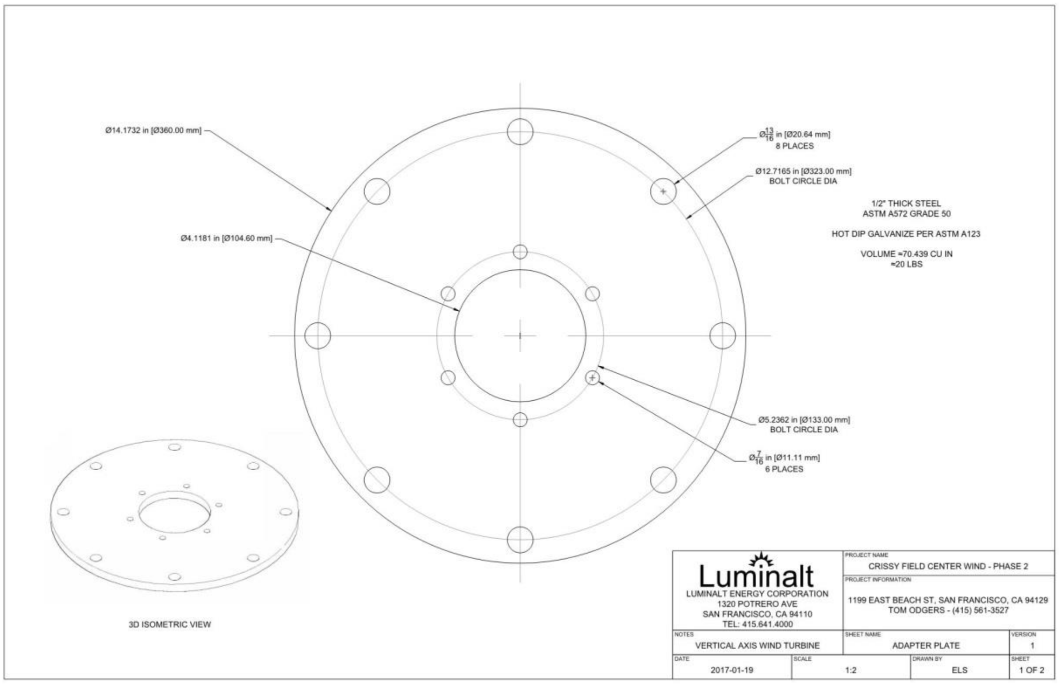


Figure 1: UGE Anchorage Detail, calculated and stamped by consulting structural engineer Plump Engineering Inc.

Flange Adaptor Plate for Omniflow Turbines

The team assessed that the Venco towers remaining from Phase I would adequately support the new Omniflow units. Luminalt designed an adaptor plate to affix the turbines to the existing flange on the Venco towers. See figure 2:



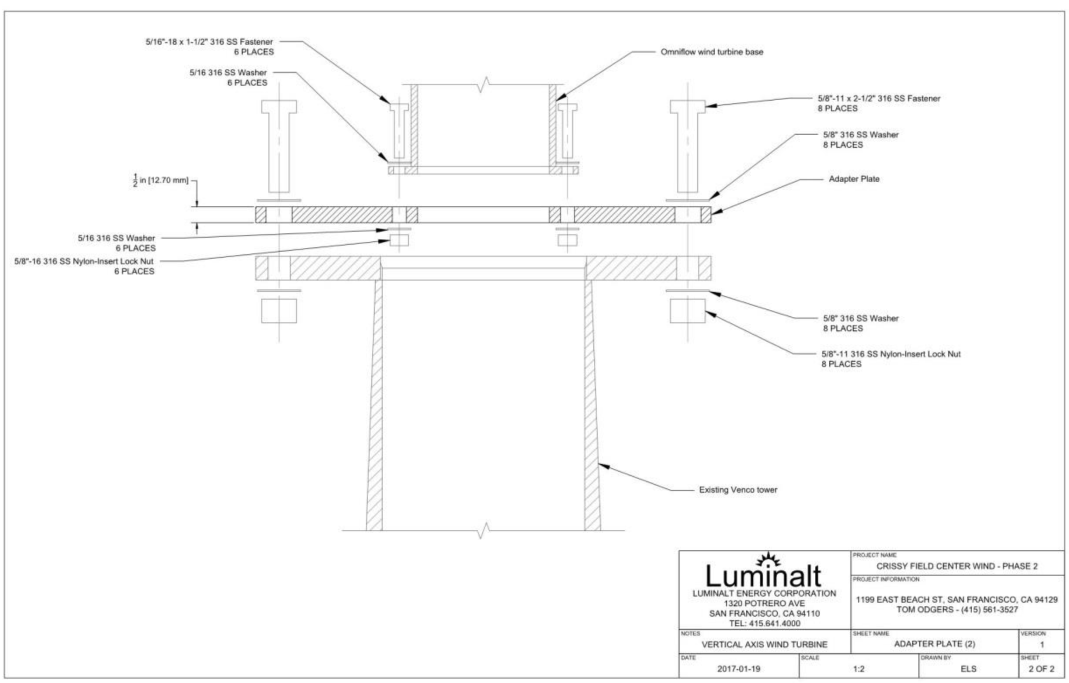


Figure 2: OmniFlow Adaptor Plate for (E) Venco Towers

Armature for New Anemometers

The wind speed and direction data requirements for Phase II necessitate the addition of several new anemometers, which are to be affixed to the turbine towers. Luminalt designed armatures to mount the new equipment:

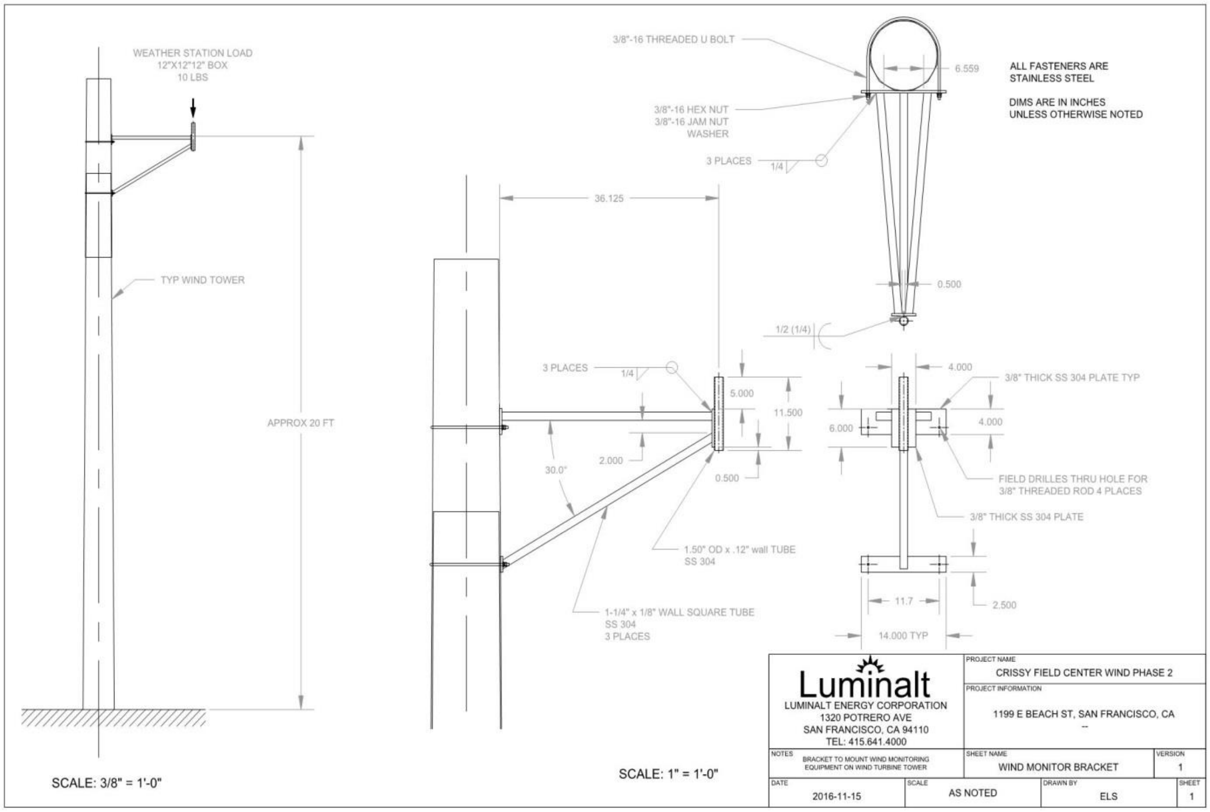
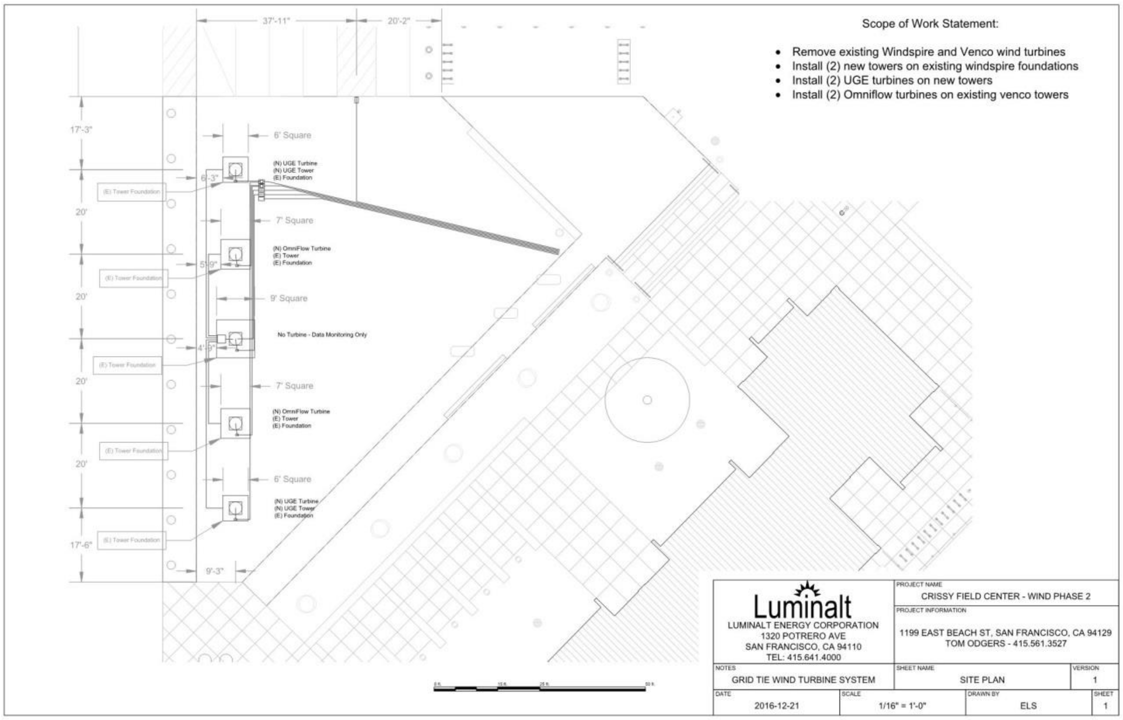
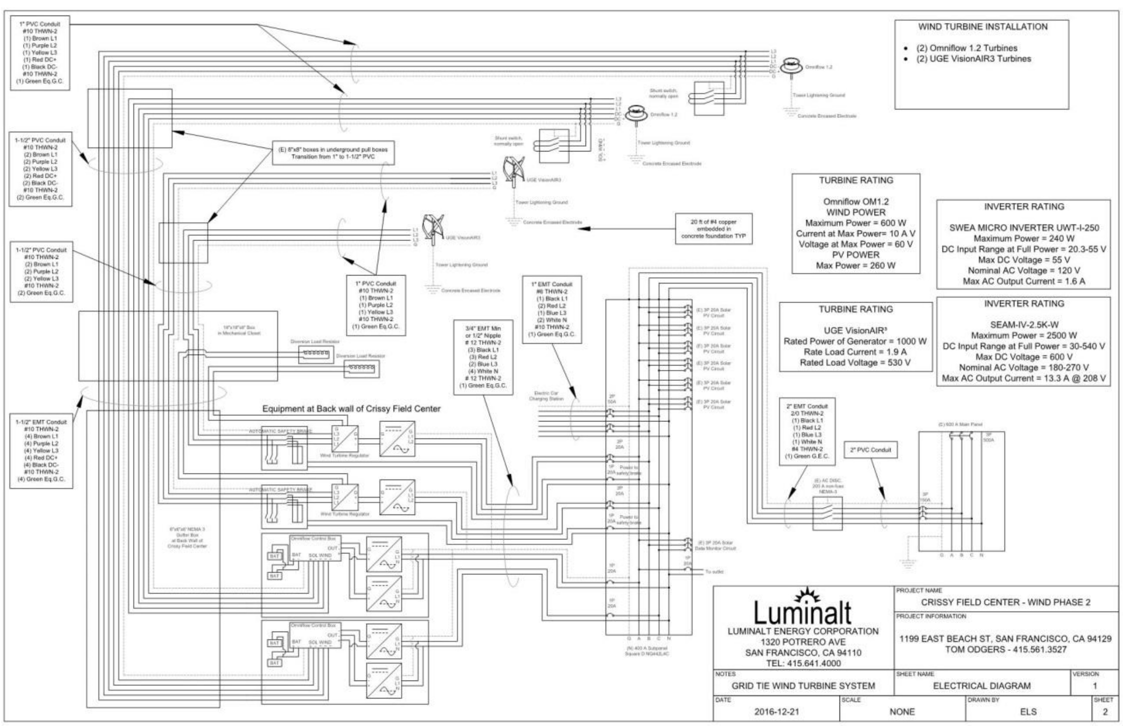


Figure 3: Armature for New Anemometers

Site Installation

To accommodate the new turbines and monitoring equipment, Luminalt developed new site plans, electrical schematics and trenching plans, as shown on sheets 1-3 below.





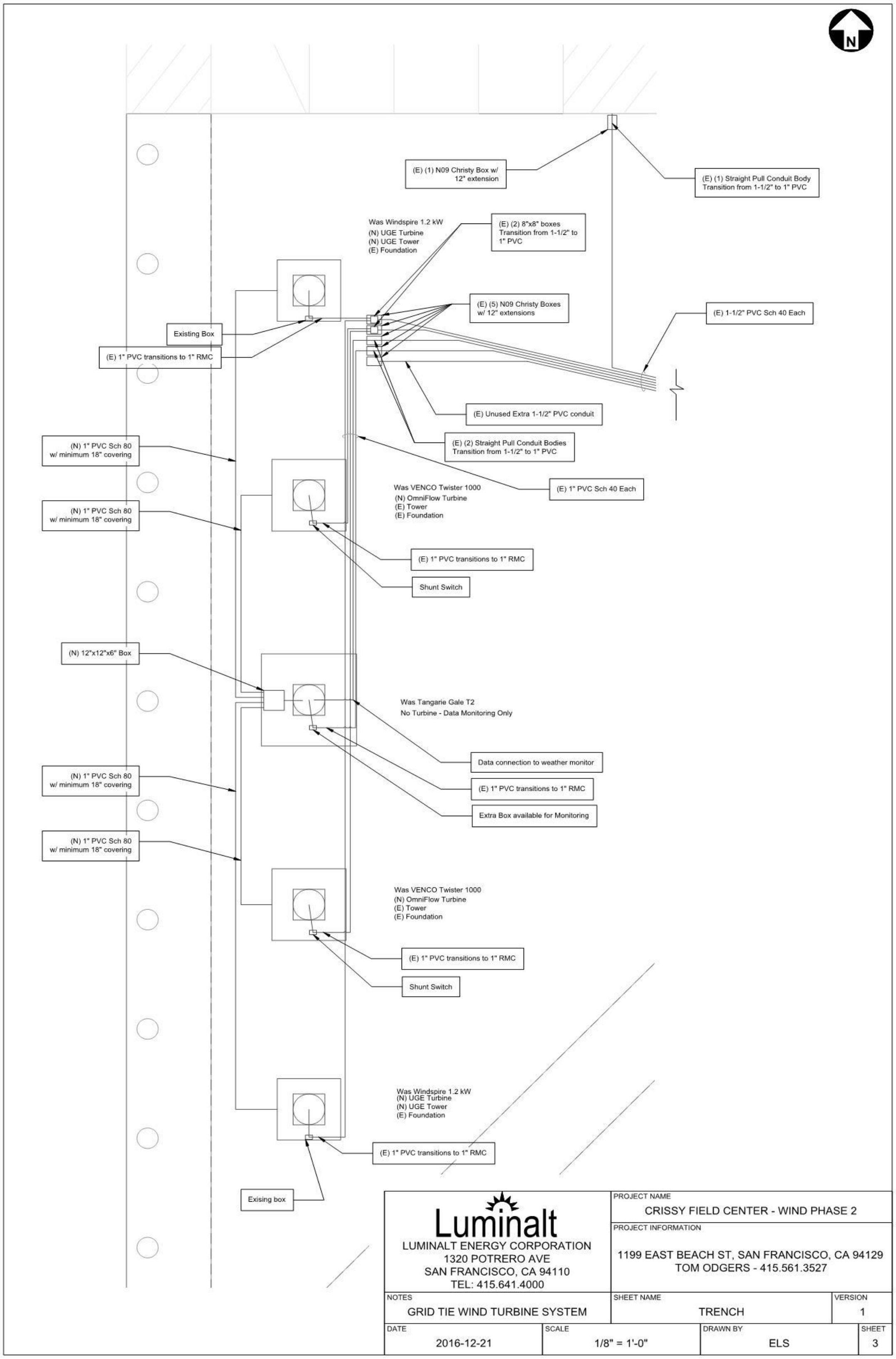


Figure 4: Phase II Installation Plans (Cont.)

Data Acquisition System Protocol

For the new DAS design, the team at Loisos and Ubelode sought to both enhance the earlier system's data collection capacity and correct for the correlation issues identified in Phase I. The design team was able to reuse most of the installed infrastructure from the Phase I DAS system, but the requirements for phase II necessitated additions/modifications to both the physical hardware and the data collection design.

In Phase I, wind speed and turbine power output were sampled differently, the former being measured using instantaneous samples and the latter being measured using sixty second averages. For phase II, a new data collection protocol was developed; the sampling rate was standardized to 1 second for wind speed, direction and turbine power output. This enables a more precise analysis of correlations between data sets – allowing, for instance, analysis of the turbines' responses to changes in wind direction and speed.

In order to meet the new experimental requirements in Phase II, additional monitoring equipment needed to be designed and installed. To enable the investigation of on-site wind patterns associated with an "urban" wind regime, anemometers were added to each wind turbine tower.

The design for the new data protocol is described in the Loisos and Ubelode memo below:

LOISOS + UBBELOHDE
ARCHITECTURE . ENERGY

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

MEMORANDUM

DATE	11 October, 2016
TO	**Jim Maskrey** Hawaii Natural Energy Institute University of Hawaii at Manoa Honolulu, HI 96822
FROM	Nathan Brown, Associate
RE	Crissy 1-second Data Collection Protocol - DRAFT

The following describes the protocol to be used to collect wind and power data for the updated Crissy Field Center wind turbine project. The monitoring system will collect data at a 1-second interval as well as at the 10-minute interval used by the existing system. This memo summarizes the 1-second data collection protocol. We understand that new wind turbines include models by Omniflow and UGE. Sensors being monitored include wind speed and wind direction at each of the four new wind turbine towers as well as instantaneous power production by each wind turbine. The 1-second measurements will not include solar power from the Omniflow turbines.

A dedicated controller will collect 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 approximately 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 500 milliseconds of the 1-second interval.

The following table shows the sensors that will be monitored at an interval of 1 second. The deviceID and sensorID numbers will be used in the data files to differentiate data points:

	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
Wind datalogger voltage	1	17	V
Power, tower 1 (north)	10	4002	W
Power, tower 2	11	4002	W
Power, tower 3	12	4002	W
Power, tower 4 (south)	13	4002	W

Data files will contain rows as follows, where values include integer values as well as converted 32-bit floating point values:

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

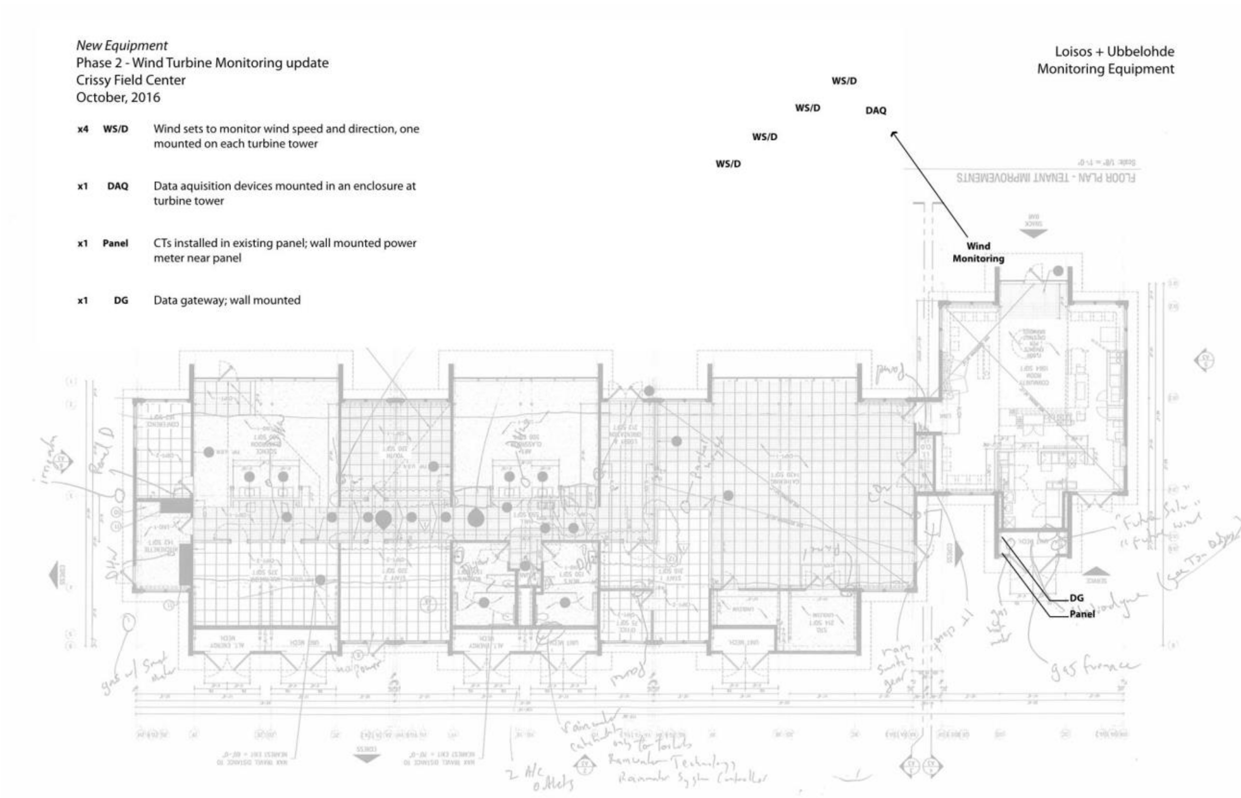
Timestamp will be given as Unix time. Data files will be saved with measured data at a 1-minute interval; the identifier will be the last timestamp measured. For instance, the head and tail of file “1476216641_data.csv” is as follows:

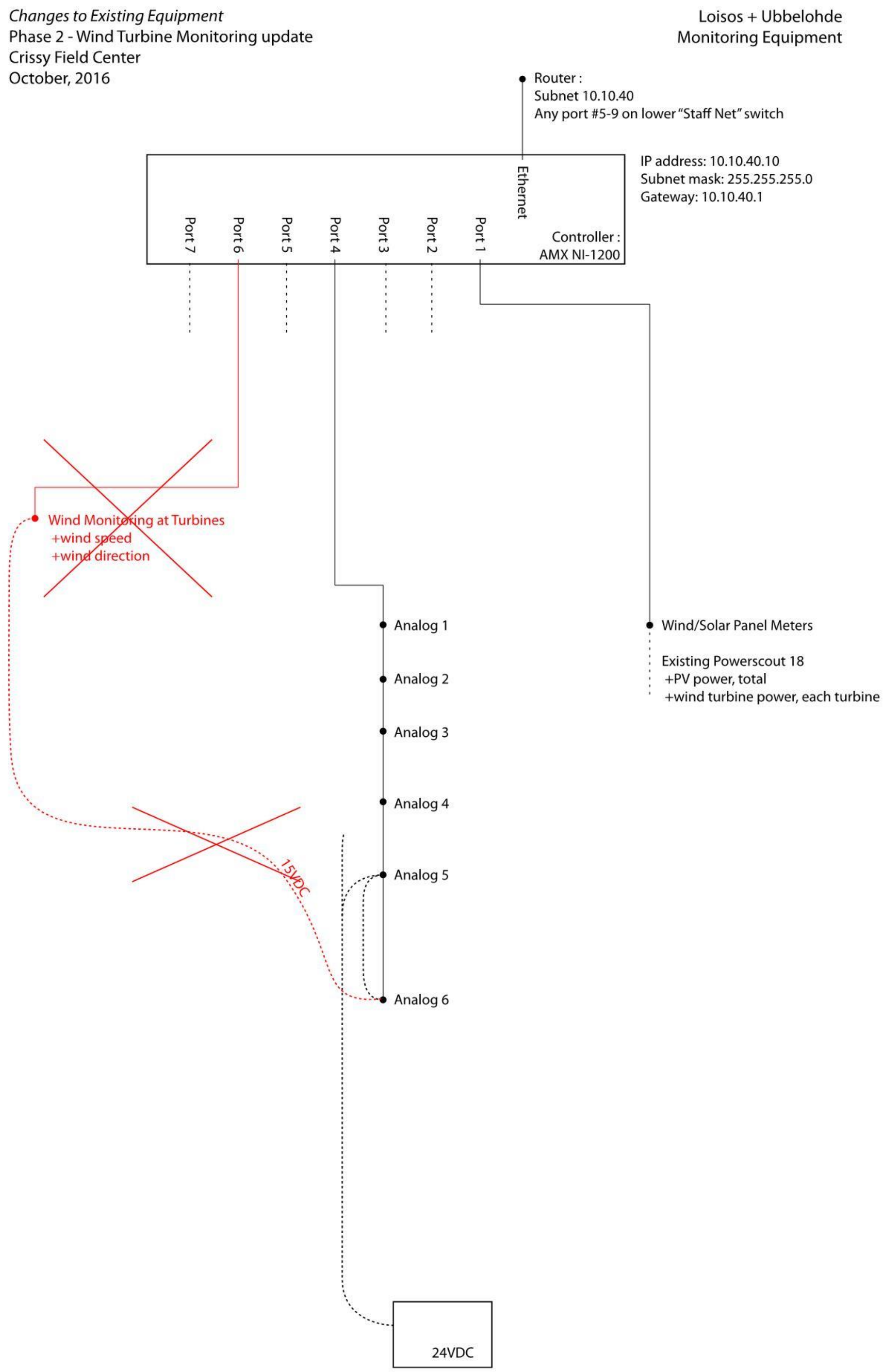
```
1476216584,10,4002,750
1476216584,1,1,3.401524622
1476216584,1,3,178.721685342
1476216584,1,5,3.391687093
1476216584,1,7,179.401611634
1476216584,1,9,3.452487622
1476216584,1,11,178.871687093
1476216584,1,13,3.401687622
1476216584,1,15,180.431115242
1476216584,1,17,12.0800933838
1476216584,11,4002,349
1476216584,12,4002,524
1476216584,13,4002,467
.
.
.
1476216641,11,4002,760
1476216641,12,4002,634
1476216641,13,4002,586
```

These data files will be transmitted via FTP to a UHM FTP server that has yet to be named. Raw data files containing unconverted floating point values (<value>=<word1>,<word2>) will also be provided as backup

Data Acquisition System Specifications and Design

To facilitate the revised data protocol, Loisos and Ubbelohde developed a design and specifications for new equipment, as shown in the installation schematic below:



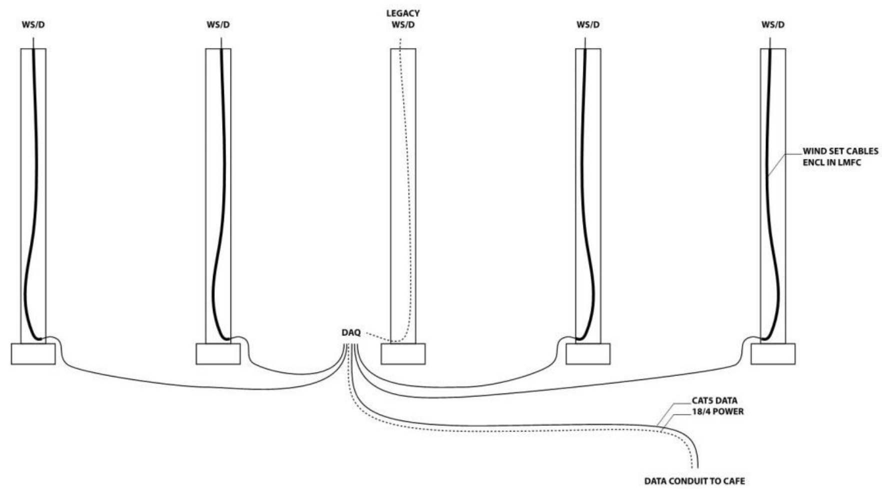


Data Acquisition System Specifications and Design (Cont.)

New Equipment
Phase 2 - Wind Turbine Monitoring update
Crissy Field Center
October, 2016

Loisos + Ubbelohde
Monitoring Equipment

WS/D : 014A + 024A Wind Set
DAQ : CR800 Datalogger, AC conversion module, and Serial interface



Data Acquisition System Specifications and Design (Cont.)

Omniflow Monitoring Challenges

The Omniflow turbines have several features that required additional analysis and engineering by Loisos and Ubelode. First, the units produce power from both a wind driven generator and photovoltaic panels. Second, the units are equipped with a battery that is charged by the wind/pv sources and is used to power the system's inverter and controller. Simple measurement of the unit's output using a currency transformer will yield aggregated, undifferentiated information from all three of these sources. Loisis and Ubelode summarize their recommendations for collecting disaggregated data specific to the turbine in the memo below:

LOISOS + UBBELOHDE
ARCHITECTURE . ENERGY

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

MEMORANDUM

DATE	25 October, 2016
TO	**Tom Odgers** Golden Gate National Parks Conservancy Building 37, Fort Mason San Francisco CA 94123
FROM	Nathan Brown, Associate
RE	Omniflow Power Monitoring

This memo describes issues related to monitoring power of Omniflow turbines in the updated Crissy Field Center wind turbine project. The objective of the power monitoring in the project is to establish a relationship between variations in wind speed and direction and variations in power produced by wind turbines. Data will be collected at a 1-second interval in order to study this relationship at a fine resolution. The electrical design of the Omniflow generator includes a source of solar power and a set of batteries; these components add complexity to the monitoring plan since wind power needs to be disaggregated from the total. To disaggregate wind data, we recommend using data collected at night to eliminate solar power data, and short-term supplemental monitoring to understand the behavior of the battery.

Description of Omniflow System

Based on documentation provided by Omniflow and a phone conversation with Pedro Ruão, the founder and CEO of the company, the Omniflow system will function in different modes depending on the voltage charge in the battery. When the battery is below 24V, all power generated is directed to charge the battery (Figure A). When the battery charge is between 24V and 26.7V, the inverter is switched on, and power is directed to the grid as well as to charging the battery (Figure B). When the battery is at 26.7V, it is fully charged, and all power is directed towards the grid (Figure C). When voltage from power production drops, the battery discharges to feed the controller and inverter (Figure D)

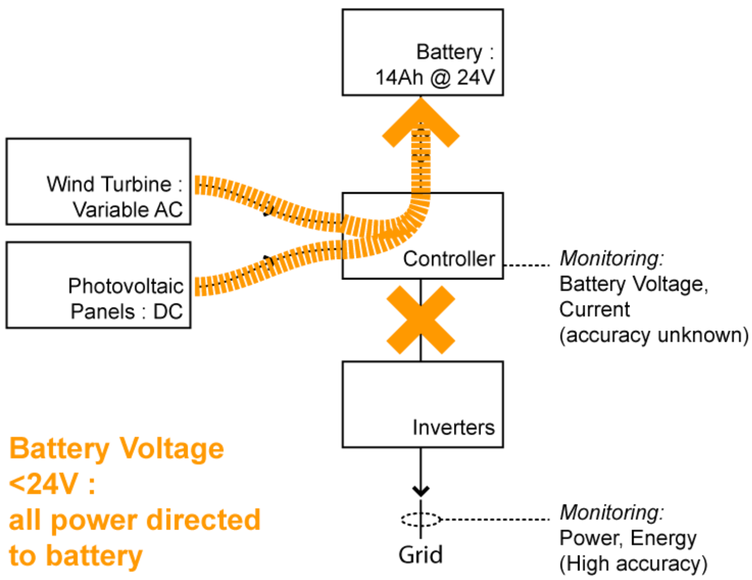


Figure A : Battery Charging Mode. Grid connection shows 0 Amps, which is less than what the turbine is actually producing.

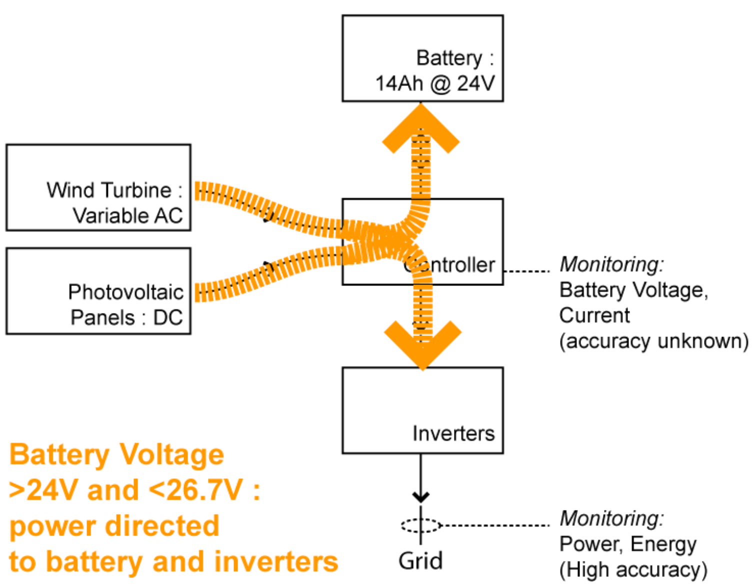


Figure B : Battery Charging and Inverter Mode. Grid connection may show more or less than the power produced by the wind turbine.

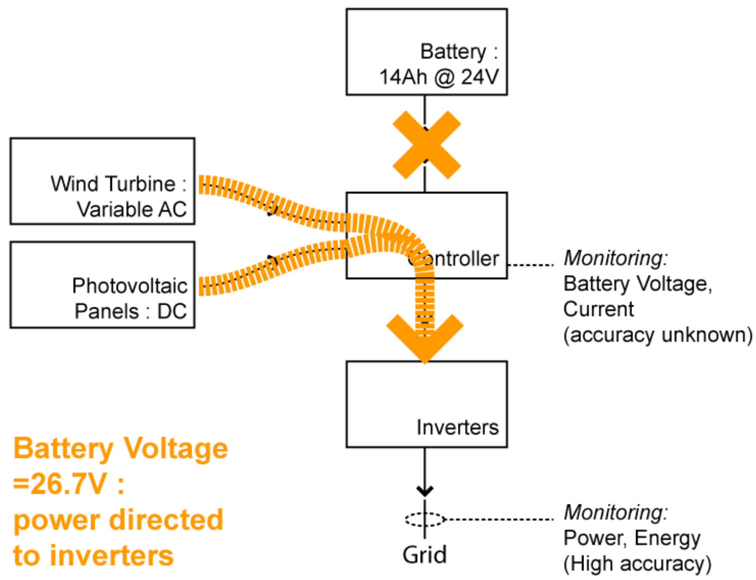


Figure C : Inverter Only Mode. Grid connection will show more than the power produced by the wind turbine.

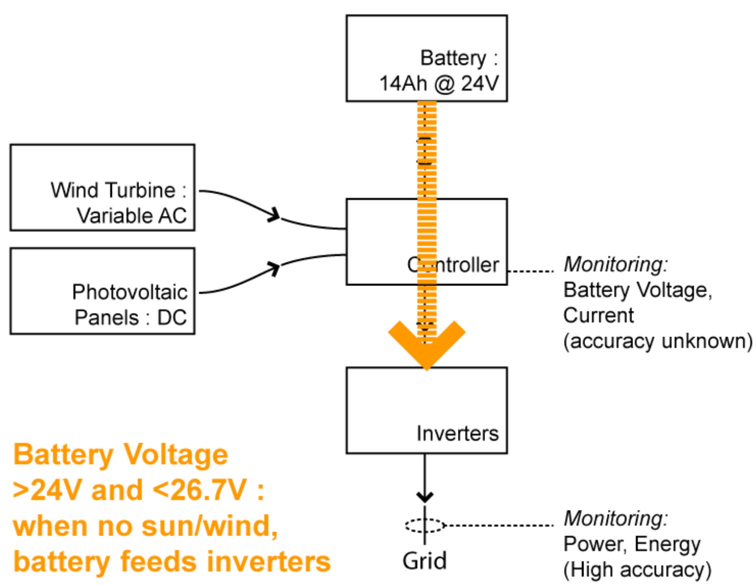


Figure D : Battery Discharging and Inverter Mode. Grid connection will show more than the power produced by the wind turbine.

The planned monitoring system includes monitoring of the electricity produced by the system as it is being transferred to the electrical panel. This measurement will be affected by system operating mode, showing less power produced whenever the battery is being charged and potentially more power when the battery is discharged. This measurement will also include any solar energy being produced.

The controller in the Omniflow system has data points available via serial connection that include battery voltage and current, although the accuracy of these measurements is questionable and the data connection to the device has not been tested. Furthermore, the monitoring system was not designed for additional serial devices and may not have the capacity for additional data collection.

In order isolate wind energy produced directly, either the energy being produced by the wind turbine must be measured directly, or the aggregate data will need to be processed to isolate times when they system is feeding exclusively wind energy directly to the grid. Direct measurement of wind energy would either involve relying upon inaccurate current measurements taken by the controller, or identifying monitoring equipment capable of measuring variable AC power. These direct measurement options are problematic due to potential accuracy issues and/or project budget constraints.

Recommended Approach

Alternatively, we recommend isolating wind turbine energy by studying times when it is night (to eliminate PV power production) and when the battery is fully charged (Figure E). By studying these times, the team should be able to eliminate any potential contribution of solar power or battery buffering. However, this approach includes risks, such as:

- The time period of buffering is unknown. If a partially filled battery charges quickly and stays charged for long periods of time, then it will be easier to disaggregate the contribution of the battery from the data. However, if battery charges and discharges frequently, then it may be difficult go disaggregate the effect.
- Diurnal wind patterns will not be captured since daytime wind data cannot be disaggregated from solar.

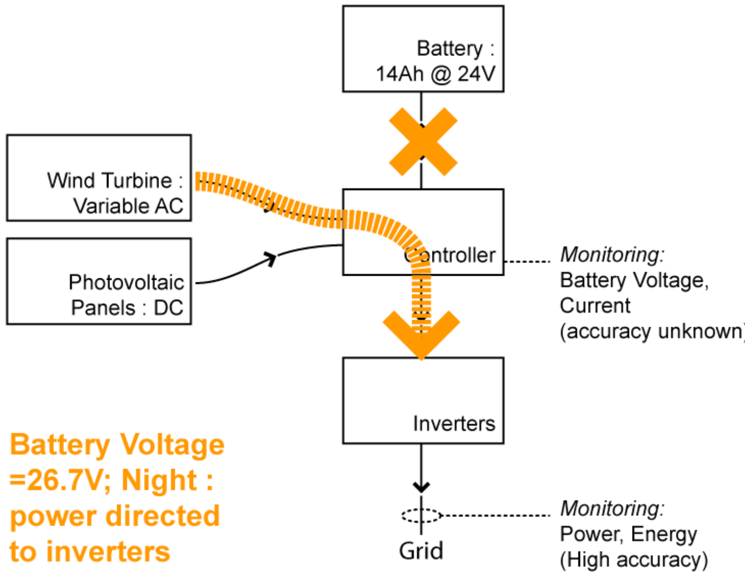


Figure E : Night Inverter Only Mode. Grid connection will show isolated wind power production

In order to understand the contribution of the battery, the team should consider short- term high resolution monitoring of battery performance to assess battery behavior and identify any further steps needed to isolate the behavior of the battery. Using the controller as a source of battery voltage data is untested. We know that data is available from the controller, but it is likely going to be difficult to integrate these data points with the specified data collection system. Rather, it may be fairly straightforward to temporarily monitor voltage using dataloggers such as those from Onset (eg, a HOBO U12-013, 0-24V input sensor and a voltage divider for an effective input range of 0-48V).

Regulatory Compliance

NEPA/NHPA review and approval was conducted for Phase I of the wind turbine projects. Documentation of the Phase I review and approval process, including elevation studies, viewshed analysis, renderings and wildlife impact considerations is available in Deliverable 1, linked here:
https://parksconservancy.box.com/s/7tm12juzyi5uqird4n3h

NEPA/NHPA review for Phase II of the Wind Turbine Project was conducted administratively under the Phase I permit.