**HERO WEC 2024 Electric Deployment Data Descriptions**

**Raw Data (TDMS, bag, and CSV Files)**

Raw data from the 2024 HERO WEC electrical deployment was recorded and saved to multiple DAQs on the system. All RO and power electronics subsystem data was recorded and saved to the onshore MODAQ system in the form of TDMS files. Buoy data was transmitted to the onshore MODAQ and saved in the form of TDMS files, however intermittent connection issues resulted in brief interruptions in the data stream received onshore and the .bag files saved to the on-buoy MODAQ system were selected for use in data processing, as connection issues did not affect the data saved to this system. Anchor load cell data was saved to the submersible DAQ in the form of CSV files. It is important to note that due to this DAQ’s location near the seabed, its clock could not be synchronized using GPS like the other DAQs and an offset was applied to this time array during data processing to sync the air spring charge time with the on-buoy DAQ timestamps. The anchor load cell DAQ is powered by internal batteries and recorded data for the entire duration of the electrical configuration deployment. The onshore MODAQ and load cell DAQs automatically applied slopes and offsets to each data stream before saving data in engineering units. Slopes and offsets were applied to data saved to the buoy DAQ during data processing. The slopes and offsets applied to each data stream as well as sensor descriptions can be found in tables 2 through 6. All slopes and offsets were calculated using NREL’s sensor calibration procedures. Diagrams of sensor locations within each subsystem along with selected calibration sheets can be found in the appendix.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **DAQ** | **Group** | **Sample Rate [Hz]** | **Data Format** | **GPS Time Sync** |
| Buoy MODAQ | AIN | 10 | bag file | Yes |
| Onshore MODAQ | VoltageAI | 2000 | TDMS file | Yes |
| Onshore MODAQ | CurrentAI | 1000 | TDMS file | Yes |
| Onshore MODAQ | PowRaw | 5000 | TDMS file | Yes |
| Load Cell DAQ | LC | 10 | CSV file | No |

***Table 1:*** *HERO WEC Sensor Groups*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Sensor Name** | **Description** | **Units** | **Instrument Output**  | **Slope** | **Offset** |
| PRESS\_OS\_2002 | Air spring pressure | psi | 4-20 mA | 15.625 | -62.500 |
| POS\_OS\_1001 | Encoder | degrees | 4-20 mA | 22.712 | -89.922 |

***Table 2:*** *AIN group sensors.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Sensor Name** | **Description** | **Units** | **Instrument Output** | **Slope** | **Offset** |
| FLOW-ON-1001 | RO subsystem inlet flow  | gpm | 4-20 mA | 1650 | -6.60 |
| FLOW-ON-1002 | Clark pump inlet flow rate | gpm | 4-20 mA | 625 | -2.50 |
| FLOW-ON-1003 | Brine discharge flow rate | gpm | 4-20 mA | 1650 | -6.60 |
| FLOW-ON-1004 | Permeate flow rate | gpm | 4-20mA | 82.50 | -0.33 |
| CND-ON-1001 | RO inlet conductivity | micro-Siemens | 4-20 mA | 6250000 | -25000 |
| CND-ON-1002 | Permeate conductivity | micro-Siemens | 4-20 mA | 312500 | -1250 |

***Table 3:*** *CurrentAI group sensors.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Sensor Name** | **Description** | **Units** | **Instrument Output** | **Slope** | **Offset** |
| PRESS-ON-1001 | RO subsystem inlet pressure | psi | 0-10 V | 15.000 | 0.000 |
| PRESS-ON-1002 | Clark pump inlet pressure | psi | 0-10V | 10.000 | 0.000 |
| PT-ON-2001 | Rectifier output voltage | V | 0-10 V | 71.397 | -0.025 |
| PT-ON-2002 | Charge controller input voltage | V | 0-10 V | 30.002 | -0.077 |
| PT-ON-2003 | Charge controller output voltage | V | 0-10 V | 10.005 | -0.024 |
| PT-ON-2004 | Battery voltage | V | 0-10 V | 10.005 | -0.024 |
| PT-ON-2005 | Pump controller voltage | V | 0-10 V | 10.005 | -0.018 |
| PT-ON-2006 | Pump A voltage | V | 0-10 V | 10.003 | -0.016 |
| PT-ON-2007 | Pump B voltage | V | 0-10 V | 10.001 | -0.013 |
| CT-ON-2001 | Rectifier output current | A | 0-10 V | 8.000 | 0.000 |
| CT-ON-2002 | Charge controller input current | A | 0-10 V | 7.999 | 0.000 |
| CT-ON-2003 | Charge controller output current | A | 0-10 V | 8.000 | 0.000 |
| CT-ON-2004 | Battery input current | A | 0-10 V | 8.000 | 0.000 |
| CT-ON-2005 | Pump controller current | A | 0-10 V | 4.999 | -0.004 |
| CT-ON-2006 | Pump A current | A | 0-10 V | 4.997 | -0.006 |
| CT-ON-2007 | Pump B current | A | 0-10 V | 4.998 | -0.007 |

***Table 4:*** *VoltageAI group sensors.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Sensor Name** | **Description** | **Units** | **Instrument Output** | **Slope** | **Offset** |
| LC-MOOR-1001 | Anchor load cell | lbf | mV/V | 4586.290 | 0.043 |

***Table 5:*** *Load cell DAQ group sensors.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Sensor Name** | **Description** | **Units** | **Instrument Output** | **Slope** | **Offset** |
| PT-ON-1001 | Generator phase 1 voltage | V | 0-10 V | 71.43 | 0.00540 |
| PT-ON-1002 | Generator phase 2 voltage | V | 0-10 V | 71.42 | 0.00893 |
| PT-ON-1003 | Generator phase 3 voltage | V | 0-10 V | 71.43 | 0.00540 |
| CT-ON-1001 | Generator phase 1 current | A | 0-10 V | 8.00 | 0 |
| CT-ON-1002 | Generator phase 2 current | A | 0-10 V | 8.00 | 0 |
| CT-ON-1003 | Generator phase 3 current | A | 0-10 V | 8.00 | 0 |

***Table 6:*** *PowRaw group sensors.*

**Processed Subsystem Array Data (Parquet Files)**

**Details of Products (columns) Added to Original Data**

**Quality Control (QC)**

Data was processed to identify and correct any out of bounds values using a QC process developed by NREL. This process compared each individual value to the sensor’s measurement limits and identified all out of bounds values. A new qc\_<original\_channel\_name> array was built for each raw data array to store these QC flag values. In these arrays, a value of zero indicates that the sensor’s reading was within bounds at a given timestamp, a value of 1 indicates that a data point was above the maximum value which the sensor can measure, while a value of 2 indicates that a data point was below the minimum value which a sensor can measure.

**Value Added Products (VAP)**

In this process, Value Added Products (VAPs) were produced to allow for thorough analysis of the data. VAPs in this data set are sorted into two categories, standard VAPs (arrays prefixed with vap\_) are arrays where raw data was modified to become usable for calculations (such as applying phase shifts to the encoder data to remove discontinuities at zero crossings), and calculated VAPs (prefixed with calc\_) are arrays where calculations were performed to provide data which could not be directly measured. Calculated VAPs are present only in the final output and summary data files.

**Zero Crossing Fixes on POS-OS-1001**

360-degree offsets were applied to portions of the encoder data to remove discontinuities at locations where the 0/360-degree mark on the encoder was crossed. This step was performed using an NREL developed script which identifies these events, checks for and removes anomalous data points recorded as the encoder outputs rapidly changes between the limits of its range, and then uses MATLAB’s [unwrap](https://www.mathworks.com/help/matlab/ref/unwrap.html) function to shift the phase angles of the data set resulting in a continuous encoder position profile. This array is saved as vap\_POS\_OS\_1001\_UW. The unwrapped encoder data was then smoothed using a Savgol filter so that the encoder velocity could be calculated later, and this array is saved as vap\_POS\_OS\_1001\_UW\_S.

**Synchronization of LC-MOOR-1001 with WEC and On-Shore DAQs**

Fixing the zero crossings on POS-OS-1001 enabled the comparison of calc\_Winch\_V and LC-MOOR-1001 to identify the timestamps of the airspring charge time and cable breaking on both the load cell DAQ and onbuoy DAQ. The load cell DAQ clock was then offset to align the air spring charge time and cable break time stamps with the timestamps of these events recorded by the GPS synchronized on buoy MODAQ system. During this deployment, it was found that the mooring DAQ clock was 15.152 seconds behind the on buoy DAQ clock and no noticeable drift occurred over the time frame of the deployment. Following this data processing, the data from each sensor along with its qc array and processed data (when applicable) was put into an individual parquet file.

**Alignment and resampling of measurements with different sampling rates**

Next, these files were grouped to build a parquet file of data for each subsystem. In this step, the anchor load cell data was resampled to the on buoy DAQ timestamps and data from PRESS-ON-1001 and PRESS-ON-1002 was down sampled to match the timestamps of the rest of the RO subsystem sensors on the CurrentAI group.

|  |  |  |  |
| --- | --- | --- | --- |
| **Subsystem** | **Abbreviation** | **Sample Rate [Hz]** | **Arrays** |
| WEC | WEC | 10 | LC-MOOR-1001 (Resampled)POS-OS-1001vap\_POS\_OS\_1001\_UWvap\_POS\_OS\_1001\_UW\_SPRESS-OS-2002WEC\_Timestamp\_NSWEC\_Datetime |
| WEC Generator | Gen | 5000 | PT-ON-1001PT-ON-1002PT-ON-1003CT-ON-1001CT-ON-1002CT-ON-1003Gen\_Timestamp\_NSGen\_Datetime |
| Onshore Power Electronics | PE | 2000 | PT-ON-2001PT-ON-2002PT-ON-2003PT-ON-2004PT-ON-2005PT-ON-2006PT-ON-2007CT-ON-2001CT-ON-2002CT-ON-2003CT-ON-2004CT-ON-2005CT-ON-2006CT-ON-2007PE\_Timestamp\_NSPE\_Datetime |
| Reverse Osmosis System | RO | 1000 | FLOW-ON-1001FLOW-ON-1002FLOW-ON-1003FLOW-ON-1004PRESS-ON-1001 (Down Sampled)PRESS-ON-1002 (Down Sampled)CND-ON-1001CND-ON-1002 |

***Table 6:*** *Electric configuration subsystems.*

Once data from each group was resampled to common timestamps, Python was then used to perform instantaneous power calculations at various points in the system along with additional calculations useful for understanding system performance. A description of each calculated array can be found in table 7. Velocity calculations were performed using Python’s np.gradient function to calculate an instantaneous velocity array from position data using numerical differentiation. This function primarily uses the central difference method; however, the forward difference and backwards difference methods are used at the beginning and end of the array to avoid the loss of data points in the velocity array.

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Subsystem** | **Description** | **Units** |
| calc\_POS\_OS\_1001\_UW\_S\_V | WEC | Encoder velocity calculated using pyhton’s [np.gradient](https://numpy.org/doc/stable/reference/generated/numpy.gradient.html) function.  | rpm |
| calc\_Winch\_V | WEC | Winch velocity. Encoder velocity multiplied by 4.5 (first stage spring return ratio) | rpm |
| calc\_Gearbox\_V | WEC | Gearbox output shaft velocity. Calc\_V\_Winch multiplied by 11.28 (gearbox ratio) | rpm |
| calc\_P\_abs | WEC | Instantaneous absorbed power (Calc\_V\_Winch \* LC\_ST\_1001). This calculation is not performed after data collection on the load cell DAQ stops. | kW |
| calc\_P\_WEC\_Electric\_Out | Gen | Instantaneous AC power input to rectifier. WEC AC power output after losses due to transmission across subsea cable. | kW |
| calc\_P\_Electric\_1 | PE | Instantaneous DC power output of rectifier | kW |
| calc\_P\_Electric\_2 | PE | Instantaneous DC power input to charge controller | kW |
| calc\_P\_Electric\_3 | PE | Instantaneous DC power output of charge controller | kW |
| calc\_P\_Electric\_4 | PE | Instantaneous DC power input to batteries | kW |
| calc\_P\_Electric\_5 | PE | Instantaneous DC power input to pump controller | kW |
| calc\_P\_Electric\_P1 | PE | Instantaneous DC power input to submersible pump #1 | kW |
| calc\_P\_Electric\_P2 | PE | Instantaneous DC power input to submersible pump #2 | kW |
| calc\_Eta\_CC\_I | PE | Instantaneous charge controller efficiency | kW |
| calc\_Filter\_DP | RO | Pressure differential across RO pre-filter | psi |
| calc\_ACC\_Flow | RO | Flow rate into onshore accumulators | Gpm |
| calc\_P\_Hydraulic\_2 | RO | Hydraulic power at RO system inlet | kW |
| calc\_P\_Hydraulic\_3 | RO | Hydraulic power at Clark pump inlet | kW |
| calc\_Recovery\_Ratio | RO | RO recovery ratio during test |  - |

***Table 7:*** *Calculated arrays.*

After performing these calculations, the common timestamp data was then broken into 30-minute duration files. These files start at each hour and 30 minutes after each hour to align with the data contained in CDIP buoy files which will be used to create test data summary files. Each of these files contains data from all sensors within a subsystem as well as all calculations relevant to that subsystem performed on the same set of timestamps. These files were saved in parquet file format and can be found in the <subsystem> Data Parquet files in MHKDR Submission 551.

**Half Hour Summary and Resource Data (Parquet Files)**

A separate Python script was then utilized to perform summary calculations on each half hour data set and output an additional parquet file summarizing device performance during each half hour of operation. These calculations include data points useful for technoeconomic analysis of the device and for understanding long term operation of coastal WECs. A complete list of summary data contained in these files can be found in table 8.

|  |  |  |
| --- | --- | --- |
| Name | Description | Units |
| Calc\_P\_abs\_AVG | Calculated average absorbed power | kW |
| Calc\_Work\_Electrical | Total electrical work done by generator during 30-minute interval | kJ |
| Calc\_P\_WEC\_Electric\_Out\_AVG | Average AC power input to rectifier during 30-minute interval | kW |
| Calc\_P\_Electric\_1\_AVG | Average rectifier DC power output during 30-minute interval | kW |
| Calc\_P\_Electric\_2\_AVG | Average DC power input to charge controller during 30-minute interval | kW |
| Calc\_P\_Electric\_3\_AVG | Average DC power output from charge controller during 30-minute interval | kW |
| Calc\_P\_Electric\_4\_AVG | Average DC power input to batteries during 30-minute interval | kW |
| Calc\_P\_Electric\_5\_AVG | Average DC power input to pump controller during 30-minute interval | kW |
| Calc\_P\_Electric\_P1\_AVG | Average DC power input to submersible pump #1 during 30-minute interval | kW |
| Calc\_P\_Electric\_P2\_AVG | Average DC power input to submersible pump #2 during 30-minute interval | kW |
| Calc\_P\_Hydraulic\_2\_AVG | Calculated average hydraulic power at RO system inlet  | kW |
| Calc\_P\_Hydraulic\_3\_AVG | Calculated average hydraulic power at Clark pump  | kW |
| Calc\_Q\_Feed\_AVG | Average flow rate of water received at RO subsystem | gpm |
| Calc\_Q\_Clark\_Pump\_AVG | Average flow rate at Clark pump | gpm |
| Calc\_Q\_Brine\_AVG | Average flow rate of brine discharge | gpm |
| Calc\_Q\_Permeate\_AVG | Average permeate flow rate | gpm |
| Calc\_Eta\_WEC | Calculated WEC efficiency (from winch to rectifier input) | % |
| Calc\_Eta\_Overall | Calculated system efficiency (from winch to Clark pump) | % |
| Calc\_Eta\_CC | Calculated charge controller efficiency | % |
| Calc\_Eta\_Rectifier | Calculated rectifier efficiency | % |
| Calc\_Volume\_RO | Total volume of water received at RO subsystem | gallons |
| Calc\_Volume\_Clark\_Pump | Total volume of water received at Clark pump | gallons |
| Calc\_Volume\_Permeate | Total volume of permeate produced | gallons |
| Calc\_Volume\_Brine | Total volume of brine discharged | gallons |
| Calc\_Tension\_AVG | Average anchor line tension | lbf |
| Calc\_Tension\_Min | Minimum anchor line tension | lbf |
| Calc\_Tension\_Max | Maximum anchor line tension | lbf |

***Table 8:*** *Summary data set values.*

Nearby ocean observing buoys and weather stations were selected to provide wave resource insight during the HERO WEC deployment. Data from CDIP 243 (NDBC 44086) and CDIP 433 (NDBC 44100) during the timeframe of the HERO WEC deployment is provided with the HERO WEC data. These buoys are Waverider type buoys and are located significantly further offshore than the HERO WEC deployment location in 20-25 m water depth. Due to the different locations and water depths of the observing buoys relative to the HERO WEC, the data from these buoys should only be used as a reference of the sea states near the HERO WEC. The shallow water waves which the HERO WEC operates in are expected to have different heights, periods, and power than the waves measured by the wave rider buoy. Data from this buoy is included only to identify general trends in the sea state and should not be used for a performance analysis of the HERO WEC in individual sea states. Wind and atmospheric data recorded by the NDBC ORIN7 station located at the Oregon Inlet Marina is also provided. A total of seven environmental data files are available consisting of one data file for the ORIN7 station, and three data files for each ocean observing buoy. Of these three files, two are raw data files, one published by NDBC, and one published by CDIP, while the third file contains wave information calculated from the CDIP wave spectral density data using MHKiT. This file contains important information such as the energy period and wave power flux.

**MATLAB Workspaces (Processed Array, Summary Data, and Resource Information)**

A MATLAB script was then used to convert the 30-minute parquet files, summary statistics file, and wave resource files into workspaces. One workspace per subsystem is available for each half hour of the test. The MATLAB summary data file contains one row per half hour interval and is intended for use in long term analyses of wave powered desalination. Wave resource information is contained within this workspace. The processed MATLAB Workspaces are accompanied by a data viewer script allowing the user to easily plot all array data over a specified timespan within the selected 30-minute interval. To use the MATLAB data viewer script, the directory variable must be set to the location of the folder containing all downloaded workspaces and the start time variable must be set to the start of the 30-minute file to be plotted. This value is entered in UTC 24 hour date string format (‘DD-MMM-YYYY hh:mm:ss’) with either 00 or 30 entered for minutes. The deployment events table in appendix B can be used to identify timespans of interest for plotting. Subsystems to be omitted from plotting can be selected by changing the values of Input.<Subsystem> from ‘YES’ to ‘NO’. The script contains two options for plotting timespans, the “default” option plots the entire 30-minute interval, and the “custom” option can be used to plot data over a user specified timespan within the selected 30-minute interval. These options can be selected by changing the value of the “Visualization.Range” variable. When using the “custom” option, the variables “Visualization.Start” and “Visualization.End” must be manually set to the desired start and end times in UTC 24-hour date string format. Once run, this script produces all applicable plots.

**Appendix A: Locations of Sensors within HERO WEC Subsystems**



***Figure 1:*** *Location of PT and CT sensors used to measure 3 phase AC electricity from generator and DC electricity after rectifier. All components in this diagram before the rectifier are part of the generator subsystem, while the rectifier and all DC components are part of the onshore power electronics subsystem.*



***Figure 2:*** *Location of PT and CT sensors after charge controller input. All components in this diagram are part of the onshore power electronics subsystem.*



***Figure 3:*** *Location of RO subsystem sensors.*



***Figure 4:*** *Location of WEC subsystem sensors.*

**Appendix B: HERO WEC Electrical Deployment Events**

|  |  |  |
| --- | --- | --- |
| **Event** | **UTC Time Stamp** | **Unix Timestamp [seconds]** |
| Air spring charged | Thu Apr 18 2024 16:42:47 GMT | 1713458567.04 |
| Batteries turned on | Thu Apr 18 2024 16:23:00 GMT | 1713457380.6 |
| WEC generator connected to onshore power electronics | Thu Apr 18 2024 16:42:47 GMT | 1713458567 |
| Batteries reach full charge | Fri Apr 19 2024 05:29:23 GMT | 1713504563 |
| First end stop event | Fri Apr 19 2024 07:06:26 GMT | 1713510386 |
| Cable breaks | Fri Apr 19 2024 07:51:32 GMT | 1713513092.36 |

***Table 9:*** *Timestamps of important events during the 2024 HERO WEC electric configuration deployment.*

**Appendix C: Sensor Calibration Sheets**



***Figure 5:*** *NREL calibration sheet for AC current transducer used to measure generator output current.*



***Figure 6:*** *Manufacturer calibration sheet for HERO WEC pressure transducer.*