**HERO WEC 2024 Hydraulic Deployment Data Descriptions**

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

Raw data from the 2024 HERO WEC hydraulic deployment was recorded and saved to multiple DAQs on the system. All RO 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 the hydraulic 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 just over four days after the HERO WEC was installed. 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 5. All slopes and offsets were calculated using NREL’s sensor calibration procedures. Diagrams of sensor locations within each subsystem 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 |
| Load Cell DAQ | LC | 10 | CSV file | No |

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

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Sensor Name** | **Description** | **Units** | **Raw Output** | **Slope** | **Offset** |
| PRESS\_OS\_2002 | Air spring pressure | psig | 4-20 mA | 15.625 | -62.500 |
| PRESS\_OS\_1001 | Hydraulic pump output pressure | psig | 4-20 mA | 9.375 | -37.500 |
| FLOW\_OS\_1001 | Hydraulic pump output flow rate | gpm | 4-20 mA | 2.477 | -9.908 |
| POS\_OS\_1001 | Encoder | degrees | 4-20 mA | 22.712 | -89.922 |

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

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Sensor Name** | **Description** | **Units** | **Raw 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 | 82.5 | -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** | **Raw Output** | **Slope** | **Offset** |
| PRESS-ON-1001 | RO subsystem inlet pressure | psig | 0-10 V | 15 | 0 |
| PRESS-ON-1002 | Clark pump inlet pressure | psig | 0-10V | 10 | 0 |

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

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Sensor Name** | **Description** | **Units** | **Raw Output** | **Slope** | **Offset** |
| LC-ST-1001 | Anchor load cell | lbf | mV/V | 4586.293 | 0.043 |

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

**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 on both the load cell DAQ and onbuoy DAQ. The load cell DAQ clock was then offset to align the air spring charge time stamp with the timestamp of this event recorded by the GPS synchronized on buoy MODAQ system. 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[[1]](#footnote-2) 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-1001  vap\_POS\_OS\_1001\_UW  vap\_POS\_OS\_1001\_UW\_S  PRESS-OS-2002  WEC\_Timestamp\_NS  WEC\_Datetime |
| Reverse Osmosis System | RO | 1000 | FLOW-ON-1001  FLOW-ON-1002  FLOW-ON-1003  FLOW-ON-1004  PRESS-ON-1001 (Down Sampled)  PRESS-ON-1002 (Down Sampled)  CND-ON-1001  CND-ON-1002 |

***Table 6:*** *Hydraulic configuration subsystems.*

Once data from each group was resampled to common timestamps, Python was then used to perform instantaneous power calculations within each subsystem along with additional calculations useful for understanding system performance. Next, the RO subsystem data and VAPs were down sampled to 10 Hz to align with the WEC subsystem data producing a single common timestamp data set for the full deployment. A description of each calculated array can be found in table 6. 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** | **Description** | **Units** |
| Calc\_V\_Encoder | Encoder velocity calculated using python’s np.gradient function | rpm |
| Calc\_V\_Winch | Winch velocity. Calc\_V\_Encoder multiplied by 4.5 (first stage spring return ratio) | rpm |
| Calc\_V\_Gearbox | Gearbox output shaft velocity. Calc\_V\_Winch multiplied by 11.28 (gearbox ratio) | rpm |
| Calc\_P\_abs | Instantaneous absorbed power ((Calc\_V\_Winch [rpm]\*(D\_Winch [ft]/2)\* LC\_ST\_1001 )/5252 [rpm\*ft\*lbf/Hp])\*0.7457 [kW/Hp]. This calculation is not performed after data collection on the load cell DAQ stops. | kW |
| Calc\_Filter\_DP | Pressure differential across RO pre-filter (PRESS\_ON\_1001 – PRESS\_ON\_1002) | psi |
| Calc\_ACC\_Flow | Flow rate into onshore accumulators (FLOW\_ON\_1001 – FLOW\_ON\_1002) | Gpm |
| Calc\_P\_Hydraulic\_1 | Hydraulic power at pump outlet ((PRESS\_OS\_1001[psig] \* FLOW\_OS\_1001 [gpm])/1714 [psig\*gpm/Hp])\*0.7457 [kW/Hp] | kW |
| Calc\_P\_Hydraulic\_2 | Hydraulic power at RO system inlet ((PRESS\_ON\_1001[psig] \* FLOW\_ON\_1001 [gpm])/1714 [psig\*gpm/Hp])\*0.7457 [kW/Hp] | kW |
| Calc\_P\_Hydraulic\_3 | Hydraulic power at Clark pump inlet ((PRESS\_ON\_1001[psig] \* FLOW\_ON\_1001 [gpm])/1714 [psig\*gpm/Hp])\*0.7457 [kW/Hp] | kW |
| Calc\_Recovery\_Ratio | RO recovery ratio during test (FLOW\_ON\_1004/FLOW\_ON\_1002) | - |

***Table 6:*** *Calculated arrays.*

**Half Hour Summary 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 7.

|  |  |  |
| --- | --- | --- |
| Name | Description | Units |
| Duck\_Wave\_Height | Significant wave height recorded at Duck WaveRider buoy (CDIP #430, NDBC #44100) | m |
| Duck\_Wave\_Period | Peak wave period recorded at Duck WaveRider buoy (CDIP #430, NDBC #44100) | s |
| Duck\_Wave\_Power | Calculated power of seastate recorded at Duck WaveRider buoy (CDIP #430, NDBC #44100) | kW/m |
| Nags\_Head\_Wave\_Height | Significant wave height recorded at Nag’s Head WaveRider buoy (CDIP #243, NDBC #44086) | m |
| Nags\_Head\_Wave\_Period | Peak wave period recorded at Nag’s Head WaveRider buoy (CDIP #243, NDBC #44086) | S |
| Nags\_Head\_Wave\_Power | Calculated power of seastate recorded at Nag’s Head WaveRider buoy (CDIP #243, NDBC #44100) | kW/m |
| Calc\_P\_abs\_AVG | Calculated average absorbed power | kW |
| Calc\_P\_Hydraulic\_1\_AVG | Calculated average hydraulic power at pump output | 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\_Pump\_AVG | Average flow rate at pump output | gpm |
| 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 inlet | 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 pump outlet) | % |
| Calc\_Eta\_Overall | Calculated system efficiency (from winch to Clark pump) | % |
| Calc\_Loss\_Transfer | Calculated losses across transfer hose | % |
| Calc\_Volume\_Pump | Total volume of water moved by hydraulic pump | gallons |
| Calc\_Volume\_RO | Total volume of water received at RO subsystem | gallons |
| Calc\_Volume\_PRV | Total volume of water discharged by pressure relief valves | 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 7:*** *Summary data.*

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 Workspace**

A Matlab script was then used to convert both the array data and summary data from parquet files to MATLAB workspaces. All data in these workspaces retains its original names from the parquet files. The processed Matlab Workspaces are accompanied by a data viewer script allowing the user to easily plot all array data over a specified timespan. To use the Matlab data viewer script, the working directory must be set to the location of the MHKDR submission 555 download and 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.

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

Diagram, schematic

Description automatically generated

***Figure 1:*** *Location of RO system sensors.*

Diagram

Description automatically generated

***Figure 2:*** *Location of on-WEC sensors.*

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

|  |  |  |
| --- | --- | --- |
| **Event** | **UTC Time Stamp** | **Unix Timestamp [seconds]** |
| Air spring charged | Thu Mar 14 2024 13:54:48 GMT | 1710424488 |
| Transfer hose connected to RO subsystem (RO bypassed) | Thu Mar 14 2024 14:00:00 GMT | 1710424800 |
| Onshore DAQ shutdown for software update | Thu Mar 14 2024 18:04:06 GMT | 1710439446 |
| Onshore DAQ resumes data collection | Thu Mar 14 2024 18:05:19 GMT | 1710439519 |
| Transfer hose disconnected from RO subsystem | Thu Mar 14 2024 18:18:00 GMT | 1710440280 |
| Flow supplied to RO subsystem by electric submersible pump for RO commissioning (RO bypassed) | Thu Mar 14 2024 18:44:22 GMT | 1710441862 |
| Electric submersible pump shutdown (end of RO commissioning) | Thu Mar 14 2024 19:54:08 GMT | 1710446048 |
| Transfer hose connected with RO engaged (NREL defined start of hydraulic test) | Thu Mar 14 2024 19:57:45 GMT | 1710446265 |
| Beginning of first RO pressure anomaly[[2]](#footnote-3) | Sat Mar 16 2024 07:50:00 GMT | 1710575400 |
| End of first RO pressure anomaly | Sat Mar 16 2024 08:40:00 GMT | 1710578400 |
| RO bypassed for system operation demonstration | Sat Mar 16 2024 15:10:56 GMT | 1710601856 |
| RO engaged | Sat Mar 16 2024 15:12:44 GMT | 1710601964 |
| Beginning of second RO pressure anomaly | Sun Mar 17 2024 07:24:00 GMT | 1710660240 |
| End of second RO pressure anomaly | Sun Mar 17 2024 13:00:00 GMT | 1710680400 |
| Beginning of third RO pressure anomaly | Mon Mar 18 2024 01:55:00 GMT | 1710726900 |
| Mooring DAQ stops recording data | Mon Mar 18 2024 12:49:36 GMT | 1710766176 |
| End of third RO pressure anomaly | Mon Mar 18 2024 13:00:00 GMT | 1710766800 |
| Beginning of fourth RO pressure anomaly | Tue Mar 19 2024 05:10:00 GMT | 1710825000 |
| Hydraulic hose punctured from abrasion against anchor line | Tue Mar 19 2024 05:25:00 GMT | 1710825900 |

***Table 8:*** *Timestamps of important events during the 2024 HERO WEC electric configuration deployment.*

**Appendix C: Sensor Calibration Sheets**

A black and white document

Description automatically generated with medium confidence

***Figure 3:*** *Manufacturer calibration sheet for HERO WEC pressure transducer.*

1. Although the mooring DAQ and on buoy MODAQ are both designed to sample at 10Hz, slight variations in the sample rates of these DAQs combined with the fact that the mooring DAQ clock cannot be GPS synchronized due to its location near the seabed necessitated the use of resampling to align these timestamps as opposed to a simple interpolation method. [↑](#footnote-ref-2)
2. During the hydraulic deployment, there were four instances of a lower pressure being recorded on the pre-filter pressure transducer (PRESS-ON-1001) than at the post-filter pressure transducer (PRESS-ON-1002).During one of these instances, the team was able to verify with the analog pressure gauge that this reading was incorrect, but a root cause for the anomalies has not been determined (e.g. electrical noise, loose connector, etc.). [↑](#footnote-ref-3)