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Version	Date	Summary
1.0	March 4, 2020	Preliminary Release for D6.5
1.1	March 11, 2020	formatting and minor revisions

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1 PURPOSE

The SeaRAY is a mobile and deployable power system for maritime sensors, monitoring equipment, communications, and other similar payloads. This Project is to design, deliver, and test a prototype low-power wave-energy-converter (WEC) that lowers the total cost of ownership and provides robust, new capabilities for customers in the maritime environment. The development of the test plan for this project is critical to progress with the design of all the systems. This ensures the project goals are met and each system's requirements are specified at an early point in the design process. This document serves as a Preliminary Test Plan for Budget Period (BP) 2 and is Deliverable 6.5 of the DOE contract for project DE-EE0008627.

2 PERFORMANCE

The following provides guidance to validate the power performance of the WEC:

- Characterize power performance following IEC TS 62600-100 TS and -102 to allow for mods to PTO
- Collect sufficient data in sea state bins with primary control method / configuration before venturing into others
- Possible variables in configuration
    - Float position (forward in aft and aft in forward)
    - Control mode (linear damping, or advanced controls)
        - Damping setting is a subset for linear damping
        - Advanced controls may also have sub settings
- Variables in sea states
    - H_{mo}, T_e
    - Direction
    - Spreading, spectral width
    - Current
    - Wind

3 SYSTEMS

System verification and validation tests are outlined in this section. These will be developed as the design progresses. C·Power uses a numbering system to group components which are used and described below.

3.1 0100 Hull

- Keel – add plates to yoke to create a keel
    - Measure angular velocity with and without the keel
    - Measure change in mooring loads with and without the keel
    - Measure yaw accumulation (spinning) with and without the keel
- Validation of performance models, loads models, and structural models
    - Measure position, velocity, acceleration
    - Measure load from mooring line
- Assess stability in range of sea states
    - Global Positioning System (GPS)/Inertial Measurement Unit (IMU) will give orientation and 6 degrees of freedom (DOF) acceleration
- Pressure test hull components

- Float return validation
- Periodic monitoring of marine growth, corrosion, wear, and other damage
    - Measure thickness of growth
    - Clean as necessary
- Check draft line periodically to assess whether marine growth or leaks are changing draft line
    - Using guide marks
    - Monitor mean position of floats with respect to the nacelle
- Post-recovery inspection for damage
- Execute maintenance item validations

3.2 0200 PTO

3.2.1 PTO Testing (includes some 0300 and 0400 system components

Verification and Validation (V&V) inspections, build quality, testing, etc. (prior to bench testing)

- Generators
    - Receiving inspection – visual Quality Control (QC)
    - Test of new Motor values as compared to design sheets
        - Phase resistance – microohm meter
        - Insulation testing – megaohm meter
        - Inductance measurement - requires special meter
    - PTO testing as outlined above
    - Testing of motor values after PTO test (resistance, insulation)
    - Testing of motor values prior to connection with power electronics (PE)
- PTO assembly
    - Mechanical weldments inspections
    - Gearbox inspections
    - Build PTO V&V
        - Alignments

PTO dyno testing – installation/calibrations/controls

- 225 kW dyno at NREL
- Dyno characterization, calibration, accuracy check
    - Prior to install
    - NTL used to measure reduction in efficiency from bearing
    - Commissioning of the integrated systems, all system checks complete and systems are ready to operate
- The dyno testing will test all systems of 0200/0300/0400
    - No-load testing
        - PTO mechanical characterization
        - Generator no-load voltage,
            - Verification of k_v voltage constant, k_e Back-emf constant
        - Back-lash, rolling resistance, break-in if necessary
        - Characterize backlash and efficiency of gearbox
    - Loaded testing
        - Slow speed ramp and steady testing
            - Control check
            - DC bus check
            - Buck-boost range check
            - Establish electrical range of operation
            - EM noise monitoring
        - Operational check

- Constant speed discrete sample points
- Controlled speed & damping ramp tests
- Calibrate PTO for various damping curves
- Control check – all operational configurations tested

3.2.2 0220 Gearbox

- Temperature sensor on high-speed shaft (HSS) side of casing

3.2.3 0230 Torque Limiter

- Encoder on low-speed shaft (LSS) and HSS to measure disengagements
- Switch to record disengagement events

3.2.4 0266 Bearings

- Lubrication sample taken from bearings
- Torque check of fasteners

3.2.5 0266 Idler Bearings

- Inspections for excessive wear
- Post inspection on amount of wear
- Visual inspection for debris in and around idler bearings

3.2.6 0280 seals

- Monitor and record bilge activity
- Visual inspection for debris in seal cavities

3.3 0300 Electric Plant

- V&V testing
    - Receiving Inspection
    - Monitoring/recording of all sensor data to achieve all system objectives
    - Verify all operations and reset contingencies in addition to V&V
    - Verification of all communications routes
    - Bench Testing (3-phase variac used as input to electrical system) completed prior to dyno
        - Build & inspect electrical system
        - Controls – testing/refinement of insulated-gate bipolar transistor (IGBT) control with varied parameters
            - Validation of Snubber design during testing
        - DC bus controls
        - Battery charging testing
        - Umbilical power testing
    - Testing of anticipated SCADA control modes
        - Damping - torque-control based speed
        - Position control, about zero point at low sea state
    - Testing of strategic Fault modes
        - List to be determined
- PTO dyno testing as outlined above
- Commissioning
    - Receiving Inspection
    - Continuous monitoring and recording of key parameters
    - Normal operation:
        - Power consumption of all auxiliary systems WEC efficiency calculations
    - Fault analysis

        - Simulation of fault isolation on various systems
    - Maintenance operations (1100 Operations)
        - As determined by post failure repair strategy of the FMECA
        - Limited number of operations as determined to be necessary to be tested at sea while deployed.
        - Categorical list to be determined
    - Fault analysis and external reset testing via HMI
    - Test External reset testing via HMI

- Normal deployed operation - Continuous monitoring for and recording of key parameters and operations according to all remaining modes of operation which are to be tested while deployed.
    - Receiving Inspection
    - Show operations according to all remaining modes of operation which are to be tested while deployed.
        - Normal operation
        - Transit operations
        - Installation and Removal Operations
        - Maintenance reduced
        - Normal stop, shut down, & start-up
        - Multiple control modes
    - Fault simulation (repeat of strategic faults which have already been performed on land, proving fault recovery at sea)
        - Over-speed events
        - Failed cooling system, reduced cooling capability
        - Emergency stop, shut down, & start-up
        - Disconnect from energy storage (WEC)
        - Disconnect from energy Storage (Subsea?)
        - Survival of Loss of Umbilical cable electrical connection
    - Maintenance operations (1100 Operations)
        - As determined by post failure repair strategy of the FMECA
        - Limited number of operations as determined to be necessary to be tested at sea while deployed.
        - Categorical list to be determined
- Power consumption monitoring during all modes of operation and wide array of sea states
- Monitoring of parameters and recording of alarm events
- High frequency data logging attempted under all sea state bins under normal control
- High frequency data logging during alarm events
- High frequency data logging during all tested modes of operation and test events
- Acceleration test of equipment enclosures with hardware installed

3.4 0400 SCADA

- V&V of all systems prior to deployment to confirm all component operations
    - Monitoring/recording of all sensor data to achieve all system objectives
    - Verify all operations and reset contingencies in addition to V&V
    - Verification of all communications routes and redundancy auto switching
    - Verify all alarms and fault recovery expected during test conditions and actual events
    - Confirm communications for all systems for temp/humidity health
- Normal Operation Testing

- Monitoring/recording of all sensor data to achieve all system objectives
- Comparison of all sensors during benign conditions for drift/failure
- Verification of all communications routes and redundancy auto switching
- Data server health monitoring and data transfers to shore health
- Verify all alarms and fault recovery expected during test conditions and actual events
- Monitor all systems for temp/humidity health

3.5 0500 Auxiliary Systems

3.5.1 0520 Safety & Emergency Systems

- V&V of all systems prior to deployment to confirm all component operations
- Confirm all safety & emergency events through surveillance and other means to validate reporting
- Verify emergency protocols performed during test events
- Compare response to feedback of all informing sensors (flood, bilge, vessel motions, etc.)

3.5.2 0530 Thermal Control of PE Enclosures

- V&V Operations
  - Confirm data range and resolution of appropriate sensors
- Normal operation: continuously monitor and record key parameters
  - Temperature/humidity/pressure of compartments
  - Conductivity/salt in air measurements
- Observation of performance with respect to climate variation
  - Performance effect of heat sink temperature (air/water heat sink)
- Fault analysis
  - Coordinate loss of cooling with 0210/0300/0560 testing if applicable
- Maintenance operations (1100 Operations)
  - As determined by post failure repair strategy of the FMECA
  - Limited number of operations as determined to be necessary to be tested at sea while deployed.
  - Categorical list to be determined

3.5.3 0550 Aids to Navigation

- Monitor function and visibility of all equipment to surrounding vessels
- Compare position/heading feedback with other onboard sensors
- Active location beacon monitoring
- Amber light – monitor active and function properly
- Maintenance operations (1100 Operations)
  - As determined by post failure repair strategy of the Failure Mode, Effects & Criticality Analysis (FMECA)
  - Limited number of operations as determined to be necessary to be tested at sea while deployed.
  - Categorical list to be determined

3.5.4 0560 Cooling System

- Monitor cooling system performance metrics under all operating conditions
- Test reduced functionality cooling performance (all contingency modes)
- Normal operation: continuously monitor and record key parameters
  - Temperature/pressure/flow
- Fault analysis
  - Loss of cooling for climate control
  - Loss of cooling for generator

- Maintenance operations (1100 Operations)
    - As determined by post failure repair strategy of the FMECA
    - Limited number of operations as determined to be necessary to be tested at sea while deployed.
    - Categorical list to be determined

3.5.5 0570 Bilge

- V&V prior to deployment
    - Ensure operation of the Bilge system (if utilized)
    - Monitor bilge to determine leak rate and location
- Normal Operation testing
    - Monitor bilge to determine leak rate
    - Determine secondary measurement systems for bilge system

3.5.6 0580 Surveillance

- V&V prior to deployment
    - Calibration and confirmation of lever arms for Inertial Measurement Unit (IMU) system
    - Calibration and confirmation of lever arms for Global Positioning System (GPS) antennas
    - Confirmation of Automatic Identification System (AIS) functionality (including backup battery)
- Utilize for monitoring of all test conditions and diagnostics during deployment
    - Confirmation of valid lever arms for GPS antennas
    - Confirm AIS signal information is sent

3.5.7 0590 Met-Ocean Monitoring

- This system will only need testing if additional components are defined to be included on SeaRAY

3.6 0600 Outfit & Furnishings

3.6.1 0640 Internal and External Paint

- Periodic inspections for marine growth and corrosion
- Anodes material decay

3.7 0700 Mooring/Umbilical Cable

- Record yaw accumulation to characterize amount of twist during deployment
- Measure loads mooring line
- Weathervaning assessment
    - Using wave measurements (from Navy WaveRider) and yaw orientation measurement (from GPS/IMU unit), determine how well the WEC aligns with waves
- Watch circle assessment
    - Using GPS position to monitor watch circle
    - Monitor for station drift during benign conditions, indicating anchor movement
    - Monitor for extreme even positions to indicate anchor movement or failures
- Periodic monitoring of mooring lines and hardware for corrosion, marine growth, fish bites, other damage
- Periodic monitoring of anchor embedment
- Monitoring of parameters and recording of alarm events
    - Position, heading, loads

    - Compare with met-ocean data for model validation
- High frequency data logging attempted under all sea state bins under normal control
- Monitor communications and electrical connectivity for fault conditions

3.8 Subsea Garage

- Validate subsea electrical performance
- Monitor oceanographic equipment
- Ensure tether management functions at depth
- Power-on/power-off seafloor payload
- Full charge cycle to test seafloor battery bank capacity

4 GLOSSARY

AIS	Automatic Identification System
BP	Budget Period
C·Power	Columbia Power Technologies Inc.
DOE	Department of Energy
DOF	Degree of Freedom
EDR	Engineering Design Requirements
FMECA	Failure Modes, Effects and Criticality Assessment
GPS	Global Positioning System
HMI	Human-Machine Interface
HSE	Health, Safety and Environment
HSS	High Speed Shaft
ICD	Interface Control Document
IGBT	Insulated-Gate Bipolar Transistor
IMU	Inertial Measurement Unit
LSS	Low Speed Shaft
PE	Power Electronics
PTO	Power Take Off
QC	Quality Control
SOW	Scope of Work
V&V	Verification and Validation
WEC	Wave Energy Converter