COLUMBIA POWER TECHNOLOGIES

power from the next wave

Direct Drive Wave Energy Converter

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1 OBJECTIVES

The objective of the LandRAY project is to demonstrate the feasibility of the novel PTO design and electric plant through verification and validation testing. The design and engineering of the systems and sub-system are verified and validated during the manufacturing, pre-assembly, and inspections. The 5MW dynamometer testing validates the capability of the 0200 power takeoff (PTO), 0300 electric plant and 0400 Supervisor Control and Data Acquisition system to meet the operating requirements. The dynamometer testing also demonstrates the reliability of the novel generator design for use in real seas as part of Columbia Powers wave energy converter (WEC). A successful test of the unique segmented large diameter design with rail bearing system and fiberglass reinforced plastic (FRP) structure will confirm ability to reduce cost of energy on future WEC PTO systems. The testing objectives are to advance the maturity of the technology and validate performance calculations.

2 OPERATING PRINCIPLES

There are ten stages of LandRAY dynamometer testing. During each stage of testing personnel will adhere to a high standard of quality and safety. The following outlines the general guidelines for operations. All dynamometer testing will be conducted in accordance with this Test Plan and the NREL Standard Operating Procedures (SOP).

2.1 NREL standard operating procedures (SOP).

While participating in activities at the NREL 5MW dynamometer all authorized workers shall read and sign the NREL SOP. A work safety planning and risk assessment will be submitted which will cover all activities of the LandRAY project. Activities will include detailed hoist & rigging/lift plans.

- *5MW_SafeOperatingProcedure.pdf*

2.2 Health, Safety & Environment (HSE)

The guidelines for safety and health hazards and environmental hazards are included in the NREL SOP. The SOP includes information on hazards, procedures, and controls for:

- Rotating equipment
- Pinch points and crushing
- Hoisting and lifting
- Electrical hazards
- Unattended dynamometer operations
- Hydraulic oil pressure
- Slippery surfaces
- Confined spaces
- Working above 4 feet
- Noise
- Elevated temperatures
- Chemical spills
- Fires
- Emergency Response Procedure
- Lock Out Tag Out (LOTO) Procedure

2.3 Personnel Training

The training requirements for specified workers in the NWTC dynamometer building will be specified in the NREL Required Training Plan. All workers participating in activities at the NWTC dynamometer building are trained as defined by:

- *NWTC_RequiredTrainingPlan.pdf*

2.4 Operational Procedures

The steps outlined in section IV A. Drive Train Test Procedures will be used to prepare for and test the LandRAY PTO in the 5MW NWTC dynamometer. The systems tasks, assembly, and testing will occur according to each Stage of testing. Procedural changes require system engineer(s) and test director approval and documentation. Changes will be documented in the master copy of test document. This applies to assembly procedures, design changes, assembly changes, system task documents, and test procedures.

2.5 Records

Documentation and data records are paramount for successful completion of the project. Results from the LandRAY project shall be recorded, archived and analyzed. (LR-EDR-G1.docx, Section 2.6)

- Data historian – All data from PTO testing
- Video monitoring – videos of NREL testing with live webcam
- Photos – document all equipment and assemblies with photography
- Log book – Maintain written & digital logs of all actions and events
- Documents – develop and maintain associated test documents

3 NWTC 5MW DYNAMOMETER OVERVIEW

The 5 MW dynamometer drivetrain includes a torque limiter, a high speed brake, high and low speed shaft speed and position, and calibrated high and low speed shaft torque transducers. The torque limiter protects the gearbox from excessive torque due the motor inertia in the case of a fault, transient, or other undesired operation. The brake is used in the case of a power outage.

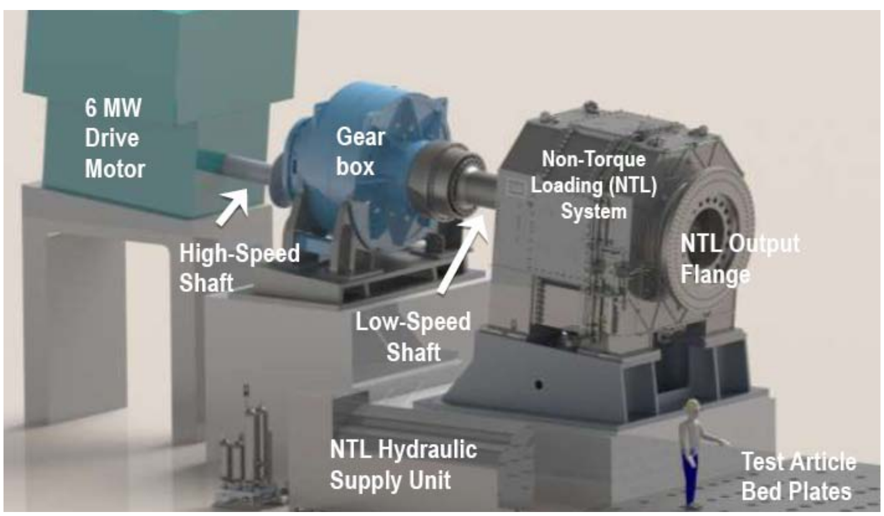

Figure 1. NWTC 5MW dynamometer driveline

3.1 Supervisory Control

The 5MW dynamometer has three levels of control; high level system control, a Facility PLC (Programmable Logic Controller), and Fault/Shutdown system. The high level control system provides real time control of the dynamometer motor and NTL system. The Facility PLC monitors for faults and provides system parameter overview to operator. The PLC code is thoroughly tested and is not to be changed during testing. The PLC protects the systems from accidental or intentional harm and insures personnel safety. The Fault/Shutdown System can initiate an Emergency stop (Estop) or Emergency

Power Off(EPO), and can lock out the motor VFD (variable frequency drive) and NTL system for safety. The Estop is a VFD controller stop within one minute with no detrimental system effects. The EPO isolates all electrical systems, activates a mechanical brake stop and initiates fire control as needed.

3.2 Data Acquisition

The 5 MW dynamometer has a distributed data acquisition system (DAS) based on National Instruments' deterministic Ethernet platform [1]. The system allows for noise-immune analog to digital conversion at several locations the facility. Fiber optic communication is used between locations and the primary data acquisition in the control room.

3.3 Controllable Grid Interface (CGI)

The CGI will provide the test article interface between LandRAY 0300 electric plant (Siemens Motion2Grid) and the NWTC utility grid. The CGI also allows for frequency and voltage control of the grid interface and fault testing [1].

3.4 General Dynamometer Procedures

The following general operating procedure applies to the start-up and shut-down of NREL 5MW dynamometer [1]. The procedure allows to data and control checks and preparation for next test sequence. For each dynamometer test these general operating steps will be followed as governed by the test director.

1. *Assign roles and responsibilities to dyno team members.*
2. *Record all significant events, settings, and file locations in dyno logbook.*
3. *Verify maximum load, speed, and displacement settings appropriate for the next test sequence*
   - Set data and set-up for test/trial sequence defined by Columbia Power
4. *Clear dynamometer highbay, place warning signs, and turn on warning lights*
5. *If required, turn off highbay heaters and turn on highbay air handler(s)*
6. *Start acquiring 50 Hz data before operation of motor and NTL. In doing this, it ensures that the data will capture all normal and any unexpected events during start-up and testing.*
7. *Continue acquiring 50 Hz data during testing except as may be required for specific test sequences. Command the NTL to apply tare loads so as to minimize all loads on the test drivetrain mainshaft. Then begin slow rotation of the test drivetrain mainshaft. Around 60 seconds of data will be sufficient.*
   - Perform test sequence as define by Columbia Power Test/Trials Plans
8. *Upon completion of testing, shut down of the VFD and NTL, stop data acquisition.*
   - Continue testing for all test trials, repeat steps as necessary
9. *Copy data and log book entries to the NWTC file server.*
10. *Return the dynamometer to the appropriate non-test condition*

3.5 LandRAY Interfaces

The interfaces between the LandRAY project and the 5MW dynamometer are detailed in Columbia Power document *LR-ICD-G1.docx*. The NREL interfaces are as follows:

- *LR-ICD-G1.pdf*

3.5.1 Low Speed Shaft Adapter

Between the main shaft of the PTO system and the low speed shaft of the 5 MW dynamometer there is a shaft adaptor plate which rigidly connects the two systems. A steel adaptor plate is provided by Columbia Power for connection to the dynamometer. It is installed prior to the LandRAY PTO.

3.5.2 Test Stand

The test stand holds the PTO system at 5° degree incline and provides rigid structural connection to the floor of the dynamometer. A steel frame structure bolts to the FRP PTO structure and mates with the dynamometer floor bolt pattern.

3.5.3 Electric Power Connection

A 480V to 13,200V delta-wye pad mount transformer will be provided to connect the output of the Siemens 630kW ALM (active line module) and AIM (Active Interface Module) grid supply modules to the NWTC utility grid interface.

3.5.4 Instrumentation

The WEC 0400 SCADA (Supervisory Control And Data Acquisition) system will interface with the NREL Data Acquisition Real Time Controller. Systems will operate independently with interlocking fault and shutdown controls.

3.5.5 Cooling Systems

The PTO Cooling system skid composed of manifolds which create stator cooling loops will be interfaced with NREL cooling skid with pump controls and forced air heat exchanger. The Electric Plant enclosures are force air cooled to dynamometer atmosphere.

3.5.6 Non-Torque Loading (NTL)

The non-torque loading non-torque loading (NTL) system will be used during PTO shaft, main bearing, secondary bearing and seal characterization. The NTL will also be used during real seas simulations to mimic actual shaft loads. The NTL system can apply axial thrust loads, lateral and upward radial forces, and pitch and yaw moments. The actuators are oriented long the axis of the shaft, 5° from vertical. During the set up procedure, the weights of the dynamometers drivetrain are measured and applied to zero the resultant main shaft loading, called "*tare loads*." The NTL specifications and main bearing specifications are shown in Table 1.

Table 1 Non-torque loading verses bearing design specification

	500 MW MTS NTL Capability	Bearing Design Specification
Moment (MNm)	7.2	7.8
Radial force (MN)	3.2	3.9
Axial force (MN)	4	3.9

A matrix of NTL loads will be used for sweeping radial and axial loads during no-load testing. NTL loads during real seas are defined in time series formatted for NREL MTS NTL load controller.

3.6 Coordinate Systems

There are two coordinate systems used in the NWTC 5 MW dynamometer [1]; the *facility* and *hub* coordinate systems. The facility defines position in the dynamometer facility highbay building and the hub coordinate system is aligned with the 5° inclined shaft. The X-axes are aligned westward, downwind from the main shaft. The Z-axes is aligned upward, toward the ceiling. The Y-axes are aligned southward, towards the drive-thru lane. For the hub coordinate system at 5° incline, the yaw moment is about the Z-axis (M_{ZZ}) and the pitch moment is about the Y-axis (M_{YY}). The facility area directions are defined with regards to upwind and downwind with regards to the test article, normally a wind turbine. The azimuth angle of rotation, or theta position, is the angle of rotation clockwise from 0° being upward while viewing upwind toward the dynamometer shaft.

3.7 NREL Instrumentation

The following NREL instrumentation will be used for LandRAY analysis. The LandRAY SCADA system will communicate with the 5MW dynamometer data acquisition system to acquire the following signals.

3.7.1 Mainshaft Speed and Angle of Rotation

The low speed shaft (LSS) is outfitted with an encoder which provides a quadrature signal to the high speed counter time module. The speed/position module provides signals to the dynamometer data acquisition system.

3.7.2 Mainshaft Torque

The mainshaft torque is measured by a custom torque spool between the gearbox and the NTL on the LSS. The spool consists of two sets of eight gauges around the outer circumference. The spool is calibrated by in place and data signal is sent to the dynamometer data acquisition system.

3.7.3 NTL Loads and Displacements

The NTL calculates forces from pressure transducers located at each one of the actuators. The loads are defined at the connection to the mainshaft. There are also displacement sensors at each actuator and shaft displacement is recorded with respect to the mainshaft. The signals are processed by the dynamometer data acquisition system.

3.7.4 Dynamometer Control Interface

The LandRAY SCADA system will acquire real time data from the NREL dynamometer controller.

- Emergency Stop – controlled stop
- Emergency Power Off – Electrical disconnection, also initiated by fire alarm
- Control data, start, stop, data set, trial verification

3.7.5 Power Quality Monitor

The electrical output of the Motion-to-Grid (M2G) system will be analyzed by and NREL power quality monitor in addition to the information available from the M2G system. Parameters monitored include by not limited to:
Voltage

- Voltage
- Current
- Power
- Power factor
- Total harmonic distortion (THD)

3.7.6 Cooling System Data

The PTO stator segments will be cooled by NREL cooling skid which contains a pump, controller, forced air heat exchanger, flow meter and National Instruments I/O control interface. The SCADA system will interface with the cooling skid to control and monitor cooling per the test plan

3.7.7 Micron Optics Fiber Optic Strain Gauges

NREL is providing a Micron Optics, optical strain gauge interface module. The FRP structure will have embedded strain gauges to allow for validation of the structural finite element analysis.

3.7.8 Vibration System

Vibration sensors are installed to provide vibration of the motor, gearbox and NTL system. Vibration measurement may be used in conjunction with LandRAY vibrations for cancelation of any feed through noise.

3.7.9 Temperatures& Humidity

The ambient temperature of the highbay can be used for further performance analysis.

4 TEST PREPARATION

4.1 Overview

The dynamometer testing will be conducted upon completion of all system reviews and verification. The LandRAY testing is an integrated system test that is divided into stages I through VII to systematically characterize all the components of the PTO. Stages I through III characterize the main bearings and shaft seals. The stage IV parameterization of the generator allows Siemens to tune the motor modules (MoMo) to the generator segments for precision control. The steady state and oscillating generator testing further characterizes the PTO systems. Upon verification of the characterization results, real seas testing will commence. The real seas' testing simulates torque, speed, and non-torque loads (NTL) of the WEC in the ocean. Real seas testing will cover a range of controls sweeping dominant wave climates. The dynamometer testing also includes extreme seas testing and any additional follow-on testing prompted by initial data analysis. The LandRAY tests will be conducted in a sequence which allows for verification of proper assembly, safety measures and control of each test.

4.2 System Readiness Required Documents for NREL Operations and Testing

Prior to each stage of testing the system readiness requirements must be fulfilled. The system task documents are divided into the prerequisites and tasks for each stage of testing. The tasks are described in the following documents:

- *NREL Work Safety Planning and Risk Assessment Document.pdf*
- *NREL LandRAY Hoist & Rigging/Lift P*
- *LR-Task-0210.pdf* — *Stator Segments Tasks Document*
- *LR-Task-0220.pdf* — *Rotor Segments Tasks Document*
- *LR-Task-0230.pdf* — *Electrical Bus Tasks Document*
- *LR-Task-0240.pdf* — *PTO Structure Tasks Document*
- *LR-Task-0250.pdf* — *PTO Shaft and Rotor Tasks Document*
- *LR-Task-0260.pdf* — *Main Bearings Tasks Document*
- *LR-Task-0270.pdf* — *Stator Cart Tasks Document*
- *LR-Task-0280.pdf* — *Main Seals Document*
- *LR-Task-0300.pdf* — *Electric Plant M2G Tasks Document*
- *LR-Task-0400.pdf* — *Control & SCADA Tasks Document*
- *LR-Task-0560.pdf* — *Cooling System Tasks Document*
- *LR-Task-0570.pdf* — *Bilge Tasks Document*
- *LR-Task-0580.pdf* — *Surveillance Tasks Document*
- *LR-Task-1045.pdf* — *Dynamometer Tasks Document*
- *LR-Task-1060.pdf* — *Test Equipment Tasks Document*
- *LR-Task-1070.pdf* — *Test Fixture Tasks Document*

4.3 LandRAY Fault Response Testing

Prior to the start of the first dynamometer test, the fault response systems of the 5MW dynamometer and the LandRAY system will be checked. The purpose of fault response verification is to minimize risk to equipment and personnel by ensuring that all fault response systems are fully operational. Each fault sensor will be tested to ensure that the proper signals are sent, and that the dynamometer and LandRAY PTO are shutdown accordingly.

4.4 Test Readiness Review

Before each stage of testing the test readiness review meeting and operations walk through is performed. The test director conducts an overview of the operating configuration, safe operating procedures, roles and responsibilities of all with all test personnel.

- Work Safety Permits (WSP)
- Verification of approved SOP
- Verification of approved test plan
- Verification of approved quality control checks
- Verification of equipment interface checklist complete
- Verification of LandRAY installation complete per design
- Walk-through inspection and safety verification complete
- Safety briefing and contingency operating procedures

5 STAGE I – MAIN BEARING TESTING

Stages I through IV develop the frictional losses of the generator. Windage loss for this ultra low speed generator is negligible and will not be considered for analysis. The stage I test assembly includes the main bearing, secondary bearing, rotor shaft, and center frame assembly without the main seals engaged. Stage I testing covers the break-in period, constant speed, oscillating operation, and NTL loading performance analysis for the main bearing. As a result of stage I the main bearing will be fully characterized and prepared for stage II testing.

5.1 Stage I System Readiness Requirement Check-list

Each of the following systems are assembled, inspected, and verified according the system task lists. The system engineer verifies the system is complete and informs the test director that the system is ready for testing:

- ☐ 0240 PTO Structure Stage I Tasks complete
- ☐ 0250 PTO Shaft and Rotor Stage I Tasks complete
- ☐ 0260 Main Bearings Stage I Tasks complete
- ☐ 0280 Main Seals Stage I Tasks complete
- ☐ 0400 SCADA Stage I Tasks complete
- ☐ 0580 Surveillance Stage I Tasks complete
- ☐ 1070 Test Fixtures – Frame Structure Stage II Tasks complete
- ☐ NREL 5MW Dynamometer Stage I complete and ready for testing.

5.2 Stage 1 Main Bearing Testing:

Record all trial information on the LR-G1-Trial Input Data Spread Sheet. Between trials process data and perform require checks per the system task lists.

5.2.1 Main Bearing Break-in Test

Per the manufactures specifications there is no break-in period for the bearing. The initial test of the bearing will distribute the grease evenly and check that rolling resistance is as expected.

- *Load Trial input data for main bearing break-in:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify speed ramps up slowly
  - Verify speed run continuously at set speeds (e.g. 1, 5, 10, 15, and 20 rpm)
  - Check for torque plateau at each speed and ensure normal rolling characteristics

5.2.2 Main Bearing Constant Speed Test

- *Load Trial input data for main bearing constant speed Trials:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify each trial according to constant speed testing set
  - Perform visual inspection between trials as necessary

5.2.3 Main Bearing Oscillating Test

- *Load Trial input data for main bearing oscillating Trial:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify oscillating position control command verses actual
  - Run all trial analysis points on the amplitude and period matrix
  - Perform visual inspection between trials as necessary

5.2.4 Main Bearing Constant Speed Test with NTL

- *Load Trial input data for main bearing constant speed Trials with NTL:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify each trial according to constant speed testing set
  - Perform visual inspection between trials as necessary

5.2.5 Main Bearing Oscillating Test with NTL

- *Load Trial input data for main bearing oscillating Trials with NTL:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify oscillating position control command verses actual
  - Run all trial analysis points on the amplitude and period matrix
  - Perform visual inspection between trials as necessary

6 STAGE II – SECONDARY BEARING TESTING

The stage II test assembly includes the secondary bearings, main bearing and complete PTO structure and frame assembly without the main seals engaged. Stage II testing covers the break-in period, constant speed, oscillating operation, and NTL loading performance analysis of the secondary bearing. The stage II results are used to isolate secondary bearing performance. As a result of stage II the main and secondary bearings will be fully characterized and prepared for stage III testing.

6.1 Stage II System Readiness Requirement Check-list

Each of the following systems are assembled, inspected, and verified according the system task lists. The system engineer verifies the system is complete and informs the test director that the system is ready for testing:

- Stage I Complete
- 0210 Stator Segments Stage II Tasks complete
- 0220 Rotor Segments Stage II Tasks complete
- 0230 Electrical Bus Stage II Tasks complete
- 0240 PTO Structure Stage II Tasks complete

- ☐ 0250 PTO Shaft and Rotor Stage II Tasks complete
- ☐ 0260 Main Bearings Stage II Tasks complete
- ☐ 0270 Stator Cart Stage III Task complete
- ☐ 0280 Main Seals Stage II Task complete
- ☐ 0400 SCADA Stage II Tasks complete
- ☐ 0560 Cooling System Stage II complete
- ☐ 0570 Bilge Stage II complete
- ☐ 0580 Surveillance Stage II complete
- ☐ 1060 Test Equipment – Pressurized water Stage II Tasks complete
- ☐ 1070 Test Fixtures – Frame Structure Stage II Tasks complete
- ☐ NREL 5MW Dynamometer Stage II complete and ready for testing.

6.2 Stage II Secondary Bearing Testing:

Record all trial information on the LR-G1-Trial Input Data Spread Sheet. Between trials process data and perform require checks per the system task lists.

6.2.1 Secondary Bearing Break-in Test

Per the manufactures specifications there is no break-in period for the bearing. The initial test of the bearing will distribute the grease evenly and check that rolling resistance is as expected.

- ☐ *Load Trial input data for Secondary bearing break-in:*
    - o Follow general dynamometer operating procedure and initiate Trials.
    - o Verify speed ramps up slowly
    - o Verify speed run continuously at set speeds (e.g. 1, 5, 10, 15, and 20 rpm)
    - o Check for torque plateau at each speed and ensure normal rolling characteristics

6.2.2 Secondary Bearing Constant Speed Test

- ☐ *Load Trial input data for Secondary bearing constant speed Trials:*
    - o Follow general dynamometer operating procedure and initiate Trials.
    - o Verify each trial over full range of speed up to 23.8 rpm.
    - o Perform visual inspection between trials as necessary

6.2.3 Secondary Bearing Oscillating Test

- ☐ *Load Trial input data for Secondary bearing oscillating Trial:*
    - o Follow general dynamometer operating procedure and initiate Trials.
    - o Verify oscillating position control command verses actual
    - o Run all trial analysis points on the amplitude and period matrix
    - o Perform visual inspection between trials as necessary

6.2.4 Secondary Bearing Constant Speed Test with NTL

- ☐ *Load Trial input data for Secondary bearing constant speed Trials with NTL:*
    - o Follow general dynamometer operating procedure and initiate Trials.
    - o Verify each trial over full range of speed up to 23.8 rpm.
    - o Perform visual inspection between trials as necessary

6.2.5 Secondary Bearing Oscillating Test with NTL

- ☐ *Load Trial input data for Secondary bearing oscillating Trials with NTL:*
    - o Follow general dynamometer operating procedure and initiate Trials.
    - o Verify oscillating position control command verses actual
    - o Run all trial analysis points on the amplitude and period matrix

- Perform visual inspection between trials as necessary

7 STAGE III – SHAFT SEAL TESTING

The stage III test assembly includes the complete PTO assembly without the stator segments engaged and without the rotor segments installed. Stage III testing covers the break-in period, constant speed, oscillating operation, and NTL loading performance analysis of the main seals. The stage III testing occurs in three steps; step one is with only the outer seal engaged, step two is with only the inner seal engaged, and step three is will both engaged. The results of stage III are used to isolate and analyze the main seals performance, fully characterize the seals under different loads and pressures, and prepared for stage IV testing.

7.1 Stage III – Shaft Seal System Readiness Requirement Check-list

Each of the following systems are assembled, inspected, and verified according the system task lists. The system engineer verifies the system is complete and informs the test director that the system is ready for testing:

- ☐ Stage II complete
- ☐ 0280 Main Seals Stage III Tasks complete
- ☐ 0400 SCADA Stage III Tasks complete
- ☐ 1045 5MW Dynamometer Stage III complete
- ☐ 1060 Test Equipment – Pressurized water Stage II Tasks complete
- ☐ NREL 5MW Dynamometer Stage II complete and ready for testing.

7.2 Stage III – Step 1 Outer Shaft Seals Testing:

Record all trial information on the LR-G1-Trial Input Data Spread Sheet. Between trials process data and perform require checks per the system task lists.

7.2.1 Main Seals Break-in test

- ☐ *Load Trial input data for Main Seals break-in:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify speed ramps up slowly
  - Verify speed run continuously at set speeds (e.g. 1, 5, 10, 15, and 20 rpm for break-in)
  - Check for torque plateau once break in period is complete
  - Perform visual inspection between trials as necessary

7.2.2 Main Seals Constant Speed Test

- ☐ *Load Trial input data for Main Seals constant speed Trials:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify each trial over full range of speed up to 23.8 rpm.
  - Perform visual inspection between trials as necessary

7.2.3 Main Seals Oscillating Test

- ☐ *Load Trial input data for Main Seals oscillating Trial:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify oscillating position control command verses actual
  - Run all trial analysis points on the amplitude and period matrix
  - Perform visual inspection between trials as necessary

7.2.4 Main Seals Constant Speed Test with NTL

- *Load Trial input data for Main Seals constant speed Trials with NTL:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify each trial over full range of speed up to 23.8 rpm.
  - Perform visual inspection between trials as necessary

7.2.5 Main Seals Oscillating Test with NTL

- *Load Trial input data for Main Seals oscillating Trials with NTL:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify oscillating position control command verses actual
  - Run all trial analysis points on the amplitude and period matrix
  - Perform visual inspection between trials as necessary

7.3 Stage III – Step 2 Inner Shaft Seals Testing:

Record all trial information on the LR-G1-Trial Input Data Spread Sheet. Between trials process data and perform require checks per the system task lists.

7.3.1 Main Seals Break-in test

- *Load Trial input data for Main Seals break-in:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify speed ramps up slowly
  - Verify speed run continuously at set speeds (e.g. 1, 5, 10, 15, and 20 rpm for break-in)
  - Check for torque plateau once break in period is complete
  - Perform visual inspection between trials as necessary

7.3.2 Main Seals Constant Speed Test

- *Load Trial input data for Main Seals constant speed Trials:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify each trial over full range of speed up to 23.8 rpm.
  - Perform visual inspection between trials as necessary

7.3.3 Main Seals Oscillating Test

- *Load Trial input data for Main Seals oscillating Trial:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify oscillating position control command verses actual
  - Run all trial analysis points on the amplitude and period matrix
  - Perform visual inspection between trials as necessary

7.3.4 Main Seals Constant Speed Test with NTL

- *Load Trial input data for Main Seals constant speed Trials with NTL:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify each trial over full range of speed up to 23.8 rpm.
  - Perform visual inspection between trials as necessary

7.3.5 Main Seals Oscillating Test with NTL

- *Load Trial input data for Main Seals oscillating Trials with NTL:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify oscillating position control command verses actual
  - Run all trial analysis points on the amplitude and period matrix

- Perform visual inspection between trials as necessary

7.4 Stage III – Step 3 Dual Shaft Seals Testing:

Record all trial information on the LR-G1-Trial Input Data Spread Sheet. Between trials process data and perform require checks per the system task lists.

7.4.1 Main Seals Constant Speed Test

- ☐ *Load Trial input data for Main Seals constant speed Trials:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify combined seal characteristics are as expected.
  - Verify each trial over full range of speed up to 23.8 rpm.
  - Perform visual inspection between trials as necessary

7.4.2 Main Seals Oscillating Test

- ☐ *Load Trial input data for Main Seals oscillating Trial:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify oscillating position control command verses actual
  - Run all trial analysis points on the amplitude and period matrix
  - Perform visual inspection between trials as necessary

7.4.3 Main Seals Constant Speed Test with NTL

- ☐ *Load Trial input data for Main Seals constant speed Trials with NTL:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify each trial over full range of speed up to 23.8 rpm.
  - Perform visual inspection between trials as necessary

7.4.4 Main Seals Oscillating Test with NTL

- ☐ *Load Trial input data for Main Seals oscillating Trials with NTL:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify oscillating position control command verses actual
  - Run all trial analysis points on the amplitude and period matrix
  - Perform visual inspection between trials as necessary

8 STAGE IV – RAIL BEARING TESTING

The rail bearing testing stage is proposed to test the rail bearings with the absence of the generator rotor to stator cogging force interaction; therefore the rotor segments are not installed. The 30 segmented stator cart assemblies are engaged with the rotor under spring load. As a result of stage IV the rail bearings will be initially characterized and prepared for stage V testing.

8.1 Stage IV System Readiness Requirement Check-list

Each of the following systems are assembled, inspected, and verified according the system task lists. The system engineer verifies the system is complete and informs the test director that the system is ready for testing:

- ☐ Stage III complete
- ☐ 0270 Stator Cart Stage IV Tasks complete
- ☐ 0400 SCADA Stage IV Tasks complete
- ☐ 1045 5MW Dynamometer Stage IV complete
- ☐ NREL 5MW Dynamometer Stage II complete and ready for testing.

8.2 Stage IV Rail Bearing Tests

Record all trial information on the LR-G1-Trial Input Data Spread Sheet. Between trials process data and perform require checks per the system task lists.

8.2.1 Rail Bearings Break-in test

- *Load Trial input data for Rail Bearings break-in:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify speed ramps up slowly
  - Verify speed run continuously at set speeds (e.g. 1, 5, 10, 15, and 20 rpm for break-in)
  - Check for torque plateau once break in period is complete
  - Perform visual inspection between trials as necessary

8.2.2 Rail Bearings Constant Speed Test

- *Load Trial input data for Rail Bearings constant speed Trials:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify each trial over full range of speed up to 23.8 rpm.
  - Perform visual inspection between trials as necessary

8.2.3 Rail Bearings Oscillating Test

- *Load Trial input data for Rail Bearings oscillating Trial:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify oscillating position control command verses actual
  - Run all trial analysis points on the amplitude and period matrix
  - Perform visual inspection between trials as necessary

8.2.4 Rail Bearings Constant Speed Test with NTL

- *Load Trial input data for Rail Bearings constant speed Trials with NTL:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify each trial over full range of speed up to 23.8 rpm.
  - Perform visual inspection between trials as necessary

8.2.5 Rail Bearings Oscillating Test with NTL

- *Load Trial input data for Rail Bearings oscillating Trials with NTL:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify oscillating position control command verses actual
  - Run all trial analysis points on the amplitude and period matrix
  - Perform visual inspection between trials as necessary

9 STAGE V – GENERATOR PARAMETERIZATION

The generator parameterization is performed by Siemens engineers upon completion assembly stage IV. The Stage V includes the entire PTO assembly with stator segments engaged and the rotor installed. Stage V testing covers the set-up and calibration of the Siemens Motion-to-Grid system and final pole alignment of the stator segments. The stage V results are used to set the machine parameters on the motor modules. As a result of stage IV the PTO and M2G will be commissioned and ready for no-load, loaded and real seas testing.

9.1 Stage V System Readiness Requirement Check-list

Each of the following systems are assembled, inspected, and verified according the system task lists. The system engineer verifies the system is complete and informs the test director that the system is ready for testing:

- ☐ Stage IV complete
- ☐ 0210 Stator Segments Stage IV Tasks complete
- ☐ 0220 Rotor Segments Stage IV Tasks complete
- ☐ 0270 Stator Cart Stage IV Tasks complete
- ☐ 0300 Electric Plant Stage IV Tasks complete
- ☐ 0400 SCADA Stage IV Tasks complete
- ☐ 1045 5MW Dynamometer Stage IV complete
- ☐ Work Safety Permit for Stage V

9.2 Stage V Generator Parameterization Tests

The stage V testing will be directed by Siemens as necessary to commission the generator and M2G system. Record all trial information on the LR-G1-Trial Input Data Spread Sheet. Between trials process data and perform require checks per the system task lists as needed.

9.2.1 Siemens S120 Commissioning for Generator and M2G system

This section of testing is per Siemens instruction:

- ☐ *S120_CommissioningManual_012013.pdf*
- ☐ *Load Trial input data for alignment and rotational tests:*
  - o Follow general dynamometer operating procedures
  - o Follow Siemens S120 Commissioning Manual as it applies to the LandRAY
  - o Perform stator alignment procedure to align all stator poles
  - o Complete commissioning procedures

9.2.2 LandRAY Systems Commissioning Tests

Upon completion of the Siemens commissioning, Columbia Power will operate the LandRAY systems to verify functionality prior to Siemens personnel departing from the test location.

- ☐ *Load Trial input data for commissioning testing:*
  - o Follow general dynamometer operating procedure and initiate trial(s)
  - o Verify systems starts up and shut-down normally
  - o Verify system identifies pole position
  - o Verify system has torque measurement
  - o Verify system is controlled by SCADA command (e.g. damping control)
  - o Verify system SCADA diagnostics is working
  - o Verify all G1 and M2G system components are fully functional

10 STAGE VI – PTO NO-LOAD TESTING

The stage VI no-load testing covers additional rail bearing break-in period, cogging torque and no-load generator analysis. No-load testing is part of IEEE standard testing procedures.

10.1 Stage VI System Readiness Requirement Check-list

Each of the following systems are assembled, inspected, and verified according the system task lists. The system engineer verifies the system is complete and informs the test director that the system is ready for testing:

- Stage V complete – *M7.1 PTO Module build and test setup complete*
- 0300 Electric Plant Stage VI Tasks complete
- 0400 SCADA Stage VI Tasks complete
- 1045 5MW Dynamometer Stage VI complete

10.2 Stage VI PTO No-Load Tests

Record all trial information on the LR-G1-Trial Input Data Spread Sheet. Between trials process data and perform require checks per the system task lists. The trials will focus on simultaneously analyzing rail bearing rolling resistance, no-load cogging torque ripple, and stator voltage as described in the following sections:

10.2.1 Rail Bearing Break-in

- *Load Trial input data for no-load rail bearing break-in Trials:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Observe rolling resistance, cogging torque, voltage and vibration
  - Analyzed rolling resistance reduction or observe torque plateau
  - Perform visual inspection between trials as necessary

10.2.2 IEEE Standard Tests

The no-load testing in accordance to IEEE P1812 Guide for Testing Permanent Magnet Machines and IEEE Standard 115-1995, IEEE Guide: Test Procedures for Synchronous Machines Part I Acceptance and Performance Testing Part II Test Procedures and Parameter Determination for Dynamic Analysis
The following topics will be analyzed during the Stage VI – No-load testing.

- *Frictional losses*
- *Cogging forces*
  - *Performed at low speeds to reduce effect of inertia*
  - *Speeds up to 23.8rpm for full mechanical frequency analysis*
- *No-load voltage*
- *Vibration and noise*
- *Rail bearing performance*

10.2.3 No-Load Constant Speed Test

- *Load Trial input data for no-load constant speed Trials:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Observe rolling resistance, cogging torque, voltage and vibration
  - Perform visual inspection between trials as necessary

10.2.4 No-Load Oscillating Test

- *Load Trial input data for main seals oscillating Trial:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Observe rolling resistance, cogging torque, voltage and vibration
  - Verify oscillating position control command verses actual
  - Perform visual inspection between trials as necessary

10.2.5 No-Load Constant Speed Test with NTL

- *Load Trial input data for main seals constant speed Trials with NTL:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Observe rolling resistance, cogging torque, voltage and vibration
  - Perform visual inspection between trials as necessary

10.2.6 No-Load Oscillating Test with NTL

- *Load Trial input data for main seals oscillating Trials with NTL:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Observe rolling resistance, cogging torque, voltage and vibration
  - Verify oscillating position control command verses actual
  - Perform visual inspection between trials as necessary

11 STAGE VII – PTO LOADED TESTING

Loading testing is performed with the Motion2Grid system energized and current following in the stators of the generator. Loaded testing includes IEEE standard testing procedures.

11.1 Stage VII System Readiness Requirement Check-list

Each of the following systems are assembled, inspected, and verified according the system task lists. The system engineer verifies the system is complete and informs the test director that the system is ready for testing:

- Stage VI complete
- 0300 Electric Plant Stage VII Tasks complete
- 0400 SCADA Stage VII Tasks complete
- 0560 Cooling System Stage VII Tasks complete
- 1045 5MW Dynamometer Stage VII complete

11.2 IEEE Standard Tests

Loading testing is performed with the Motion2Grid system energized and current following in the stators of the generator. Performed with guidance from IEEE P1812 Guide for Testing Permanent Magnet Machines and IEEE Std 115-1995, IEEE Guide: Test Procedures for Synchronous Machines Part I Acceptance and Performance Testing Part II Test Procedures and Parameter Determination for Dynamic Analysis
The following test topics will be analyzed:

- *Locked rotor current and torque*
- *Cogging forces*
- *Temperature analysis for start-up, shut, down, rise-rates and steady state*
- *Speed - Torque tests*
- *Pull-out torque*
- *Transients testing*
- *Duty type S3 analysis (verses S9 – duty with non-periodic load and speed variations)*
- *Winding resistance at operating temperature*
- *Temperature analysis*
- *Short circuit testing*

11.2.1 Locked-rotor Testing

The objective is to characterize the torque of the generator.

- *Load Trial input data for main seals constant speed Trials:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Performed with the rotor of the dynamometer locked
  - Sweep current up to limit of torque/current for static position
  - Measure wind-up of shaft
  - Thermal Class in accordance with IEC 62114

- Perform visual inspection between trials as necessary

11.2.2 Short Circuit Testing

The objective is to characterize the short circuit fault stability and performance of the generator.

- *Load Trial input data for main seals constant speed Trials:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Perform visual inspection between trials as necessary

11.2.3 Loaded Constant Speed Tests

- *Load Trial input data for main seals constant speed Trials:*
  - Very low speed cogging torque measurement,
    - CW and CCW for hysteresis measurement
    - Record cogging and temperature of magnets
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify each trial over full range of speed up to 23.8 rpm.
  - Operational verification
    - Normal operation – generating and motoring
    - Torque measurement
    - Damping control
    - VPM – flux weakening
  - Perform visual inspection between trials as necessary

11.2.4 Loaded Oscillating Tests

- *Load Trial input data for main seals oscillating Trial:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify oscillating position control command verses actual

11.2.5 Loaded Constant Speed Tests with NTL

- *Load Trial input data for main seals constant speed Trials with NTL:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify each trial over full range of speed up to 23.8 rpm.

11.2.6 Loaded Oscillating Tests with NTL

- *Load Trial input data for main seals oscillating Trials with NTL:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify each trial over full range of speed up to 23.8 rpm.

11.3 Stage VII PTO Motor Tests:

Record all trial information on the LR-G1-Trial Input Data Spread Sheet. Between trials process data and check vibration, lubrication, and torque data are within specifications.

11.3.1 Motoring Tests

- *Load Trial input data for main seals constant speed Trials:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Pull-out torque analysis
  - Torque and position control
  - IEC duty cycles, S3, S9

11.3.2 Loaded Constant Speed Tests

- *Load Trial input data for main seals constant speed Trials:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify each trial over full range of speed up to 23.8 rpm.
  - Steady state performance analysis
  - Perform visual inspection between trials as necessary

12 STAGE VIII – REAL SEAS TESTING

The Stage VIII tests are performed to characterize the performance, operation, and fault stability of the PTO and M2G system. The real seas testing trials simulate the PTO and M2G operation in the ocean. The testing includes controller testing, operational analysis, and fault testing.

12.1 Stage VIII System Readiness Requirement Check-list

Each of the following systems are assembled, inspected, and verified according the system task lists. The system engineer verifies the system is complete and informs the test director that the system is ready for testing:

- Stage VII complete
- 0300 Electric Plant Stage VIII Tasks complete
- 0400 SCADA Stage VIII Tasks complete
- 1045 5MW Dynamometer Stage VIII complete

12.2 Normal Operation – Real Seas

The normal operation tests cover all sea climates and PTO controls used for performance validation of the PTO model in hydrodynamic simulations. The dynamometer will be controlled by theta position data sets.

12.2.1 Linear damping

Linear damping tests use a fixed linear relationship between torque and speed which saturate at the torque limit

- *Load Trial input data for main seals constant speed Trials:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Sea states from AQWA
  - Use different linear damping for each sea state
  - Perform visual inspection between trials as necessary

12.2.2 Controlled damping investigation

Controlled damping uses a feedback loop from the SCADA which allows torque command at any point in the normal operating region.

- *Load Trial input data for main seals constant speed Trials:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Sea states from AQWA
  - Use different damping controls for each sea state.
  - This section is open for all controls investigation
  - Vary the damping over full range
  - Demonstrate hardware controls for SCADA and M2G
  - Perform visual inspection between trials as necessary

12.2.3 Thermal Investigation

Controlled damping uses a feedback loop from the SCADA which allows torque command at any point in the normal operating region.

- *Load Trial input data for main seals constant speed Trials:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Sea states from AQWA
  - Use different damping controls for each sea state.
  - This section is open for all controls investigation
  - Perform visual inspection between trials as necessary

12.3 Extreme Operations – Real Seas

The PTO is designed to operation in the most extreme wave conditions. As a result of this design requirement, the PTO will be tested with simulated extreme seas real waves. The extreme wave conditions include operation in aft position, 180° rotation and return to front.

12.3.1 Mechanical Systems

The mechanical system will be tested to the most extreme levels of operation using dynamometer simulations with use real seas position with generator heavy damping and NTL loading.

12.3.2 Voltage protection

The voltage protection module will be tested during high speed events

12.3.3 Overspeed with emergency burn and disconnect

Large real seas events which initiate a generator disconnect sequence will be simulated.

12.3.4 Extreme Seas Simulations

The objective of extreme seas testing to is to development performance characteristics while operating in the highest energy sea states.

- *Load Trial input data for main seals constant speed Trials:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Define data sets
  - 1 to 3 repetitions each
  - Test mechanical systems
  - Test voltage protection
  - Test over-speed voltage protection and burn resistor
  - Perform visual inspection between trials as necessary

12.4 Energy Storage Testing

On the StingRAY WEC, the 0330 energy storage system provides power smoothing in close proximity to the power generation with connection to the DC bus link, between the 10, 107kW MoMo's and the 500kW ALM+AIM grid tie inverter. The energy storage is designed to smooth wave power peaks to within the grid regulated specification for grid connection at the deployment location. The LandRAY energy storage represents a single module unit of the complete energy storage system. Therefore LandRAY energy storage testing will occur at a lower power level.

- *LandRAY_M2G_Operations_Fault_Analysis – Confidential.pdf*

12.4.1 *Power Smoothing Operational Tests*

The power smoothing analysis is performed at a module scale. Small real seals simulations are run with energy storage connected.

- *Load Trial input data for main seals constant speed Trials:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Small sea states
  - Use different damping controls for each sea state.
  - This section is open for all controls investigation
  - Perform visual inspection between trials as necessary

12.4.2 *Fault Testing*

Faults to be are list in the fault analysis spreads sheet. Follow all safe operating procedures

- *Load Trial input data for main seals constant speed Trials:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Small sea states
  - Use different damping controls for each sea state.
  - This section is open for all controls investigation
  - Perform visual inspection between trials as necessary

12.5 Islanding Operation

Islanding operation requires power from the energy storage system to maintain the control power to the M2G system. Follow all safe operating procedures

- *Load Trial input data for main seals constant speed Trials:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Small Sea states
  - Use different damping controls for each sea state.
  - This section is open for all controls investigation
  - Perform visual inspection between trials as necessary

12.6 M2G Fault Analysis

The following cases are analyzed using the most limited case and wave conditions. A fault can happen at any time therefore each case is tested while simulating the worst possible conditions for the fault to occur. The resultant mode of operation is described in further detail in Siemens Uses Cases document. Once a fault has occurred the WEC will be considered in Maintenance and Repair mode of operation. The LandRAY testing will simulate the following case scenarios as possible:

- *LandRAY_M2G_Operations_Fault_Analysis – Confidential.pdf*

12.6.1 *Loss of SCADA command*

Simulation of a loss of commanded damping from SCADA will result in either continued power generation of controlled shut-down.

- *Load Trial input data and initiate test:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify fault response correct

12.6.2 *Encoder error during start-up*

Test simulates a failure in the encoder system during start-up by disconnecting the encoder cable from the SMC20.

- *Load Trial input data and initiate test:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify fault response correct

12.6.3 Encoder error during energy harvesting phase

Test simulates a failure in the encoder system during normal operation by disconnecting the encoder cable from the SMC20.

- *Load Trial input data and initiate test:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify fault response correct

12.6.4 Failure of the cooling system to generator

The test simulates a 0560 Cooling System fault in which all cooling to the generator is lost. The test will result in reduced power production to maintain the generator stator temperatures within operational limits. If stator segments are shut off if temperatures exceed limits.

- *Load Trial input data and initiate test:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify fault response correct

12.6.5 Over temperature in a generator segment

Simulate overheating of stator due loss of cooling water to one segment

- *Load Trial input data and initiate test:*
  - Follow general dynamometer operating procedure and initiate Trials.
    - Loss of cooling water to a signal segment
    - PTC temperature sensor fault
    - KTY temperature sensor fault
  - Verify fault response correct

12.6.6 Failure of cooling system of the M2G

Simulate failure of cooling components to M2G enclosures

- *Load Trial input data and initiate test:*
  - Follow general dynamometer operating procedure and initiate Trials.
    - Loss of cooling system to M2G enclosures
    - Over temperature in a signal enclosure
    - Temperature sensor fault in an enclosure
    - Over temperature in a MoMo
    - Over temperature in a ALM
    - Over temperature in a AIM
    - Over temperature in other key components as necessary
  - Verify fault response correct

12.6.7 Over current faults

Simulate over current in key components

- *Load Trial input data and initiate test:*
  - Follow general dynamometer operating procedure and initiate Trials.
    - Over current in a signal generator segment results in 4/5 segments on MoMo
    - Over current in a MoMo results in 5/6 of MoMos operational

        - Over current in a MoMo unbalanced load of 1 of 3 current sensors
    - Verify fault response correct

12.6.8 Over voltage and under voltage faults

Simulate over current in key components

- *Load Trial input data and initiate test:*
    - Follow general dynamometer operating procedure and initiate Trials.
        - Over voltage on the DC link
        - Under voltage on the DC link
        - Over voltage on energy storage
    - Verify fault response correct

12.6.9 Alternative Operating Configurations

Simulate power generation with less than 30 stator segments and less than 6 MoMo.

- *Load Trial input data and initiate test:*
    - Follow general dynamometer operating procedure and initiate Trials.
        - Fault in 1 MoMo results in reduced torque & power production using 5/6 MoMo
        - Fault in 2 MoMo results in reduced torque & power production using 4/6 MoMo
        - Fault in 3 MoMo results in reduced torque & power production using 3/6 MoMo
        - Fault in 4 MoMo results in reduced torque & power production using 2/6 MoMo
        - Fault in 5 MoMo results in reduced torque & power production using 1/6 MoMo
        - Fault in 1 stator results in using 4/5 stators on a single MoMo
        - Fault in 2 stator results in using 3/5 stators on a single MoMo
        - Fault in 3 stator results in using 2/5 stators on a single MoMo
        - Fault in 4 stator results in using 1/5 stators on a single MoMo
    - Verify fault response correct

12.6.10 Emergency shutdown - Freewheeling

There are number of faults which will result in PTO shut-down. This test proves the M2G shuts down safety without equipment damage while the dynamometer is still moving the generator.

- *Load Trial input data and initiate test:*
    - Follow general dynamometer operating procedure and initiate Trials.
    - Verify fault response correct

12.7 Grid Fault Analysis

The grid fault testing will be performed in accordance with IEC/IEEE guidelines and recommendations from ESBI. The NREL controllable grid interface will simulate grid faults while the PTO and M2G are operating in normal real seas.

12.7.1 Low Voltage Ride Through –LVRT

- *Load Trial input data and initiate test:*
    - Follow general dynamometer operating procedure and initiate Trials.
    - Verify fault response correct

12.7.2 Flicker coefficient calculation (at a range of Hs/Tp values)

- *Load Trial input data and initiate test:*
    - Follow general dynamometer operating procedure and initiate Trials.
    - Verify fault response correct

12.7.3 Harmonic Distortion (THD as a %)

- *Load Trial input data and initiate test:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify fault response correct

12.7.4 Voltage unbalance

- *Load Trial input data and initiate test:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify fault response correct

12.7.5 Reactive Power Control

- *Load Trial input data and initiate test:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify fault response correct

12.7.6 Active Power Control (Frequency Response)

- *Load Trial input data and initiate test:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify fault response correct

12.7.7 Grid protection functions

- *Load Trial input data and initiate test:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify fault response correct

13 STAGE IX – POST TESTING CHARACTERIZATION

Upon completion of PTO testing the component characteristics developed during the testing will be checked. The post testing characterization ensures that the components, such as the bearings and seals which experience a break-in period, have stabilized their characterized performance. If a post test varies significantly from the initial characterization test, a full component test regime will be executed.

13.1 Part 1 - Generator and Rail Bearing Post Check

The following tests are for performance validation of the PTO model in regular wave hydrodynamic simulations. The dynamometer will be controlled by theta position data sets.

13.1.1 Readiness Requirement Check-list

Each of the following systems are assembled, inspected, and verified according the system task lists. The system engineer verifies the system is complete and informs the test director that the system is ready for testing:

- Stage VIII complete
- 1045 5MW Dynamometer Stage IX complete

13.1.2 Generator Post Testing Pole Alignment Investigation

- *Load Trial input data for constant speed post check Trials:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify pole alignment information matches
  - If alignment is off perform full investigation

13.1.3 Generator Post Testing No-load Performance Investigation

- *Load Trial input data for constant speed post check Trials:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify rolling resistance and cogging profile matches
  - Verify generator no-load performance matches
  - If no-load voltage does not match

13.2 Part 2 – Main Seals Post Check

The following tests are for performance validation of the PTO model in regular wave hydrodynamic simulations. The dynamometer will be controlled by theta position data sets.

13.2.1 Readiness Requirement Check-list

Each of the following systems are assembled, inspected, and verified according the system task lists. The system engineer verifies the system is complete and informs the test director that the system is ready for testing:

- Stage IX complete
- 0200 Generator Stage IX complete
- 0300 Electric Plant Stage IX complete
- 0400 SCADA Stage IX complete

13.2.2 Seal Rolling Resistance Investigation

- *Load Trial input data for constant speed post check Trials:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify rolling resistance as compared to initial testing

13.3 Part 3 – Main Bearings Post Check

The following tests are for performance validation of the PTO model in regular wave hydrodynamic simulations. The dynamometer will be controlled by theta position data sets.

13.3.1 Readiness Requirement Check-list

- Stage IX part 2 complete
- 0200 Generator Stage IX complete
- 0300 Electric Plant Stage IX complete
- 0400 SCADA Stage IX complete

13.3.2 Seal Rolling Resistance Investigation

- *Load Trial input data for constant speed post check Trials:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify rolling resistance as compared to initial testing

14 STAGE X – NOISE TESTING

The purpose of the noise monitoring is for permitting reasons. It gives us data that we will be able to point to about low noise (expected). Put it in the plan.

14.1 Stage X System Readiness Requirement Check-list

Each of the following systems are assembled, inspected, and verified according the system task lists. The system engineer verifies the system is complete and informs the test director that the system is ready for testing:

- Stage IX complete
- 0300 Electric Plant Stage X Tasks complete
- 0400 SCADA Stage X Tasks complete
- 1045 5MW Dynamometer Stage X complete

14.2 Stage X – Noise Testing

The noise monitoring is performed with the dynamometer shut-down. The M2G runs the LandRAY as a motor with matching position profiles. The system noise is recorded.

14.2.1 Motoring Steady State testing

- *Load Trial input data for constant speed post check Trials:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify rolling resistance as compared to initial testing

14.2.2 Motoring Oscillating testing

- *Load Trial input data for constant speed post check Trials:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify rolling resistance as compared to initial testing

14.2.3 Motoring Real Seas

- *Load Trial input data for constant speed post check Trials:*
  - Follow general dynamometer operating procedure and initiate Trials.
  - Verify rolling resistance as compared to initial testing

15 ANALYSIS

During and after each test, the data gathered is analyzed by Columbia Power engineers in Corvallis OR. At any time in which there is a discrepancy in the data, tests are re-run.

15.1 Measurement Verification

Upon complete of the testing, instruments and data lines are checked for accuracy. Some sensors and data lines may develop a drift from normal reading.

15.2 Follow-up Testing

Any follow-up testing based on the completions tests above.

16 CERTIFICATION

Ocean Energy Converter Certification will be conducted by Germanischer Lloyd (GL). The assessment activities include site conditions, mechanical, electrical & structural design, safety features, as well as assessment of prototypes.

16.1 Criteria for Engineering Certification

A certification standard(s) will be agreed upon for the final design.

17 GLOSSARY

CPwr – Columbia Power
PLC – Programmable Logic Controller
PTO – Power Take Off, the system which converts mechanical wave power into electrical energy
SCADA – Supervisory Control and Data Acquisition
SOP – Standard Operating Procedure
SWP – Safe Working Procedure
ICD – Interface Control Document – controls standard for interface between system components
EMI – electromagnetic interference
ESD –Emergency Shut Down
EPO – Emergency Power Off
M2G – Motion-to-Grid, Siemens 0300 Electric Plant

18 REFERENCES

[1] H. Link, R. Wallen, V. Gevorgion, *NWTC 5 MW Dynamometer & Controllable Grid Interface Commissioning Test Plan*, NREL September 27, 2013

[2] *IEEE Std 115™-2009, IEEE Guide for Test Procedures for Synchronous Machines 2010,* IEEE 3 Park Avenue, New York, NY 7 May 2010