COLUMBIA POWER TECHNOLOGIES
power from the next wave

Direct Drive Wave Energy Converter

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1 MILESTONE 3.1: COMPONENT DESIGN REPORT/PTO DESIGN

This Report informs DOE and all team members of: the generator, mechanical and electromagnetic designs; electric plant design; dynamometer electrical and mechanical interface designs; and test stand and water tank designs (for seal testing). The report will confirm design completion of all essential elements and will cover the design details at a block diagram level. Report includes detailed inspection criteria, pre-tests and checklists to be performed in tasks 4 and 5 (M4.1, M4.2, M5.1)

2 LANDRAY DESIGN

The LandRAY systems designs are purpose built to advance the future StingRAY WEC PTO designs, to reduce the risk of new component applications and designs, and meet the interface constraints of the 5MW dynamometer at NREL National Wind Testing Center (NWTC). The LandRAY systems are numerically categorized into major groups as follows:

2.1 0200 Power Take-Off (PTO)

The PTO system comprises all structural, generator, and subsystem components which enable the conversion of the mechanical wave energy into electrical power. The PTO system interfaces with the 5MW Dynamometer (float drive arms on the WEC) on the mechanical side and the 30 cables from the stator segments to the Motion-to-Grid (M2G) system on the electrical side. The following sections, and associated documents, describe and explain the novel PTO design.

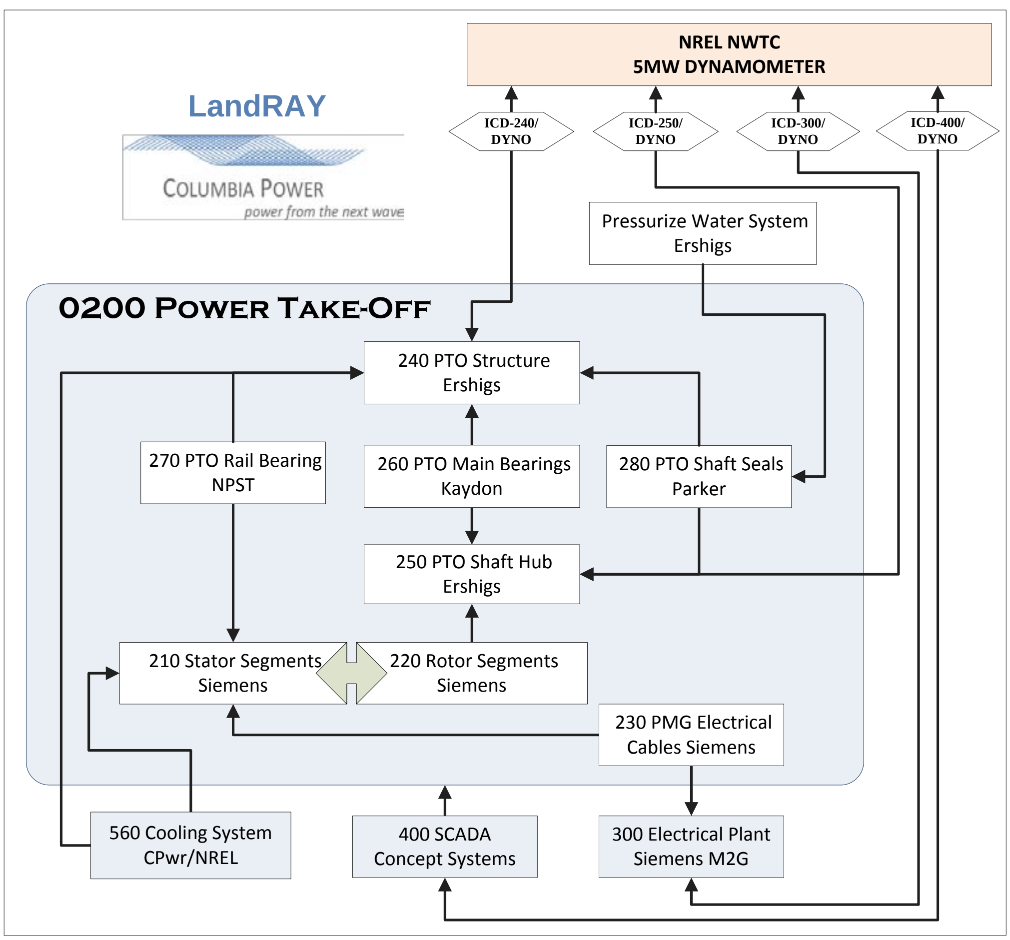

Figure 1 – Block diagram of LandRAY systems

2.1.1 0210 Stator Segments

The generator was custom designed by Siemens for Columbia Power LandRAY project. The segmented generator is designed to operate at ultra low speeds with a S3 periodic duty cycle. The 30 segments are synchronized by the M2G system and mechanically attached to the rail bearing system with T-bars.

- *400026382_01_TORQUEMOTOR Confidential.pdf*
- *400026341_01_STATORSEGMENT Confidential.pdf*
- *400026342_00_T-Nutenstein (Statorsegm.) Confidential.pdf*

2.1.2 0220 Rotor Segments

The rotor segments are composed of rare earth NbFeB magnets with laminated back-iron. The 240 rotor segments create 480 magnetic poles about the perimeter of the fiber-reinforced plastic (FRP) rotor assembly. The segments are fastened to the FRP with T-bars.

- *400026380_01_ROTORSEGMENT Confidential.pdf*
- *400026381_00_T-Nutenstein (Rotorsegm.) Confidential.pdf*

2.1.3 0225 Rotor Installation Tool

The rotor installation tool is part of the magnet handling safety protocol and helps to ensure the safety of personnel and equipment. The installation tool includes a non-magnetic rotor segment transportation box and mechanical inserting tool. The rotor installation tool mounts to the side of the FRP rotor and rigidly holds the rotor segment in-line with the T-bars. The rotor in transport box is aligned with the T-bars. Once the rotor and T-bars are aligned, the installation tool inserts the rotor along the radial direction of the T-bar until rotor is against the FRP lip back stop. The T-bars are tightened and the tool is move to the next rotor location.

- *Confidential – Rotor Installation Tool.pdf*

2.1.4 0230 Stator Cables

There are 30 electrical cables for each of the generator stators. The cables include three phase connection with ground, and two separate temperature detectors which are embedded in the back-iron of the stator segments. The cables run approximately 50 meters from each stator segment to the motor module (MoMo) connection terminal inside the M2G enclosures.

- *Siemens_6FX700_CableSpecs Confidential.pdf*

2.1.5 0240 PTO Structure

The PTO structure is made up of the housing carrier, housing end panel, housing shell, stator rail beam, housing window plank, and fixed shaft. Detail 0203 in the component drawing listed below shows each of the part’s location in the generator. These structural components are designs for LandRAY only; not up to StingRAY specifications.

- *C-13049_2014-07-25.pdf*

2.1.6 0250 PTO Shaft & Rotor

The shaft and rotor are what transfer torque from the dynamometer to the generator segments. The shaft is a large hollow steel shaft that connects the dynamometer, seals, bearings, and rotor. The rotor connects the shaft to the rotor segments. The shaft and rotor is made up of a rotating shaft, rotor carrier, rotor wheel, and rotor tire. Refer to 2.1.5 for a detailed drawing of these components.

2.1.7 0260 PTO Main Bearings

There are two bearings that transfer the forces from the waves into the WEC: the primary bearing, and the secondary bearing. The primary bearing connects the drive shaft to the nacelle tube. The secondary bearing connects the drive shaft to the generator's outer housing. These two bearings ensure coarse alignment of the generator airgap and fine alignment of the seals. These bearings will be load tested by the dyno up to their full rating. The rating for the LandRAY is the same as for the StingRAY for a 20 year life. The following component drawings are from Kaydon.

- *Main Bearing - 18092001S.pdf*
- *Secondary Bearing - 18125001S.pdf*

2.1.8 0270 PTO Rail Bearing

The PTO Rail Bearing system is used for the fine alignment of the generator airgap via a stator cart. There are 30 stator carts, each with one stator segment, which is guided by four wheels along rails mounted to the rotor tire. The following component drawings detail each part used for this system:

- *0270 Stator Cart Drawings 7-29-2014-Confidential.pdf*

2.1.9 0280 PTO Shaft Seals

The LandRAY generator uses 4 lip seals and 4 o-ring seals to keep water out of the generator and out of the dynamometer space (twice as many seals as required for StingRAY). The lip seals have an axial running surface and the o-rings have a radial static contact surface. The following are component drawings from Parker.

- *Lip Seal AR-14-103-3.pdf*
- *O-ring AR-14-112-2.pdf*

2.1.10 0281 PTO Shaft Seal Carrier

The seal carriers hold the lip and o-ring seals in place. A mechanism is attached to the seal carrier which engages and disengages the seals from the running surface. Refer to 2.1.5 for detailed drawings of the seal carriers.

2.2 0300 Electric Plant

The LandRAY electric plant represents one-half of a complete WEC design in which two identical PTO's are used. The electric plant interfaces with the 0200 PTO at the stator cables and with the 0800 collection system at the 13.2kV high side of the transformer. To prove power smoothing capability 0330 energy storage will be included as a scaled demonstration.

2.2.1 Siemens Motion-to-Grid (M2G)

The Siemens Motion-to-Grid (M2G) energy converters are built to order power electronics which are tailored specifically to take energy from renewable resources, such as wind, wave, tidal, geothermal, or biomass, and transform the variable electromechanical energy into reliable harmonic three-phase power for use on the utility grid. The LandRAY M2G has been designed to work with the 30 stator segments for wave energy generation and to meet IEEE 1547 harmonic standards and UL 1741 interconnection standards for distributed energy resources. The following Siemens documents describe the design in more detail.

- *Siemens_CPwr_LandRAY_Overview_Confidential.pdf* *Overview*
- *Siemens_56OC-1622-L-101-REV AA Confidential.pdf* *Layout*
- *Siemens_56OC-0001622-S-101 Confidential.pdf* *One-lines*
- *Siemens_1622FORM_B101_C010-60 Confidential.pdf* *BOM*

2.2.2 0330 Energy Storage

The energy storage system is a modular design which represents one module of the larger StingRAY WEC energy storage. The energy storage includes a DC/DC converter, an ultracapacitor bank, and controls which interface with the M2G system. The DC/DC converter charges and discharges the ultracapacitors to the DC bus link between the MoMos the ALM+AIM of the M2G system.

- *Siemens S120 converters 1TE32-0AA4 PM13 2013.pdf*
- *Maxwell_125vmodule_ds_1014696-7.pdf*

2.2.3 0350 Transformer

The LandRAY project will use a standard pad mount 750kVA oil filled transformer which will connect to the M2G at 480V and the NREL test article grid interface at 13.2kV. Three separate manufactures have been contacted, an Eaton transformer example is shown below.

- *Eaton_BED4499787_quote_spec.pdf*
- *Eaton_BED4499787-00001.pdf*

2.3 0400 Control & SCADA

2.3.1 0400 SCADA

The NREL dynamometer facility has a dedicated high resolution data acquisition (DAQ) system based on National Instruments (NI) hardware. The DAQ is responsible for collecting all dynamometer specific parameters and is configured to collect data from a host of NREL systems including:

- Dynamometer
  - position, speed, torque data
- Non-Torque Loading (NTL) system
  - loads and displacement data
- Cooling skid
  - Temperature, pressure, flow, fan and pump control data
- Vibration system
  - 15 accelerometer channel data
- Power quality analyzer data
- Controllable Grid Interface (CGI) data

To ensure data synchronization between the dyno and LandRAY, all DAQ data will be routed to the SCADA system in real-time allowing all data to be time stamped at a common collection point. In order to facilitate the required high bandwidth data transfer, ProfiNet will be used between the DAQ and the SCADA system. ProfiNet allows for high speed bi-directional data exchange. Data will also be sent from the SCADA system to the DAQ for NREL data archiving purposes and to facilitate dyno and cooling system control commands.

2.4 0500 Auxiliary Systems

The LandRAY auxiliary systems are limited to the following systems for the LandRAY design.

2.4.1 0520 Safety & Emergency Systems

2.4.1.1 0521 Fire Control

The 5MW dyno facility is equipped with a laser based fire detection system as well as manually operated fire pull handles throughout the building. This existing system will serve as the primary fire control system. Once activated the fire control system executes an Emergency Power Off (EPO) to all power sources within the facility. Additionally, a smoke/fire sensor located within the PTO enclosure will trigger an Emergency Shut Down (ESD) to all electric plant and dyno hardware and as well a providing operators a visual alarm notification.

2.4.1.2 0524 Access Interlocks

In accordance with NEC all LandRAY high power enclosures are equipped with access interlocks to prevent unintentional entrance into cabinets while they are energized. In the event that one of these enclosures is opened it will automatically de-energize the enclosed equipment, execute an ESD, and alert the operator.

'Do Not Enter' placards will also be placed in the highbay entrances during testing to notify personnel of the dangers present during dyno operation.

2.4.1.3 0525 Emergency Shutdown (ESD)

The Emergency Shutdown (ESD) is a hard wired safety mechanism implemented by NREL to de-energize the dyno system in the event of a hardware fault or an E-stop button in pressed. This failsafe system is connected in a normally closed wire loop. CPwr will splice into the ESD loop with their PLC and M2G systems allowing them to initiate an ESD event if either system should develop a fault condition. Upon an ESD event all power carrying CPwr equipment will be de-energized while the SCADA system will continue to collect data for diagnosis.

2.4.2 0540 Station Power

The LandRAY Station Power system provides power for all SCADA hardware. The Station Power system will operate off NREL's existing Uninterruptable Power Supply (UPS) allowing SCADA to continue collecting diagnostics data in the event of an ESD. The total power consumed by the SCADA system will be recorded in real-time which will allow designer to make valuable predictions for the StingRAY design.

2.4.3 0560 Cooling System

The cooling system provides cooling water to the 30 stator segments and interfaces with the NREL cooling skid. The NREL cooling skid has a forced air heat exchanger, cooling water pump, VFD pump drive, expansion tank, flow meter, pressure meter and temperature sensors. The cooling system contains 6 flow meter five port manifolds, 6 shut off valve five port manifold, and 2 six port manifolds which constructed of PEX tubing to create 30 stator cooling flow control loops. The cooling system connects to the cooling skid via 2" influent and effluent lines.

- *0560 Cooling System Confidential.pdf*
- *LR-FEED-0560 Confidential.pdf*

2.4.4 0570 Bilge pumping system

The bilge pumping system for LandRAY consists of a large funnel in the generator that collects all of the water, a bilge holding tank, and a pump to remove the water. See section 2.5.1 for a drawing of this system.

2.4.5 0580 Surveillance

NREL is providing access to their pan/tilt/zoom (PTZ) cameras inside the dynamometer and will place a few loose cameras inside the generator. Access to the video feed is on their network and will also be stored on hard drives locally.

2.5 1060 Test Equipment

Test equipment systems are those that are specially design to facilitate LandRAY testing, they will not be included on an ocean going buoy.

2.5.1 Pressurized Water System

The pressurized water system is used to test the seals during LandRAY testing. Compressed air will pressurize water in a tank which will be fed to the seals. Two separate system will be used, one for each seal. A level sensor in the pressure tank will record the leak rate of the seals if there is one. This piping and instrumentation diagram (PID) details the layout of the pressurized water system and the bilge pumping system:

- LR-PID-1060.pdf

2.6 1070 Test Fixtures

The test fixtures for LandRAY are the mechanical interfaces between the generator and the dynamometer. These include the structure frame and the adaptor flange.

2.6.1 1070 Structure Frame

The structure frame is comprised of steel beams that keep the generator stationary during testing. The frame will also be used to lift the generator into place.

- LandRAY Frame.pdf

2.6.2 1070 Adaptor Flange

The adaptor flange connects the output shaft of the dynamometer to the drive shaft of the generator. Refer to 2.1.5 for a detailed drawing of the flange.

3 SYSTEM PREPARATIONS

3.1 Mechanical System Preparations

- *LR-Mechanical System Preparations-G1 v1.pdf*

3.2 Electrical System Preparations

- *LR-M2G System Preparations-G1 v1.pdf*

3.3 SCADA System Preparations

- *LR-SCADA System Preparations-G1 v1.pdf*