Design of the Open-source Tidal Energy Converter (OSTEC) to Advance Marine Energy IEC Standards

M. Bichanich[1*], P. Sedigh[1], M. Wosnik[1], V.S. Neary[2], A. Bharath[3], R. Cavagnaro[4], D. Kim[2], B. Gunawan[2], K. Wakefield[2], and S. Harris[2]

[*] Presenting Author

[1] University of New Hampshire (UNH), Atlantic Marine Energy Center (AMEC)

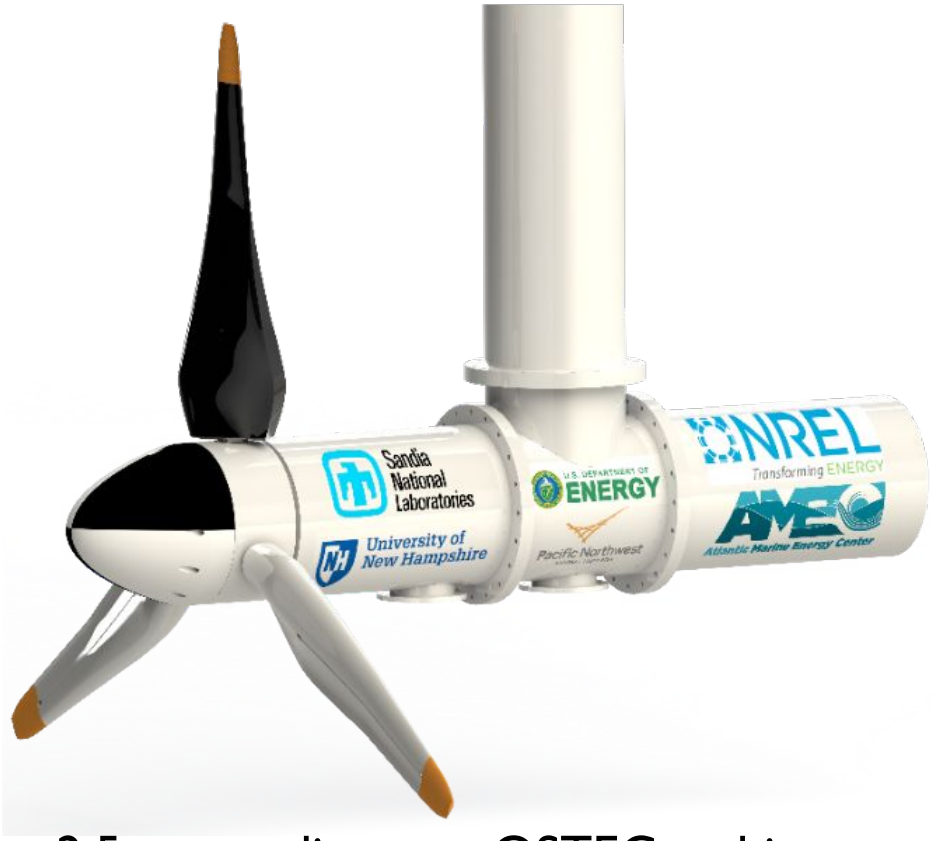
[2] Sandia National Laboratories (SNL)

[3] National Renewable Energy Laboratory (NREL)

[4] Pacific Northwest National Laboratory (PNNL)

Design Goals of the OSTEC turbine

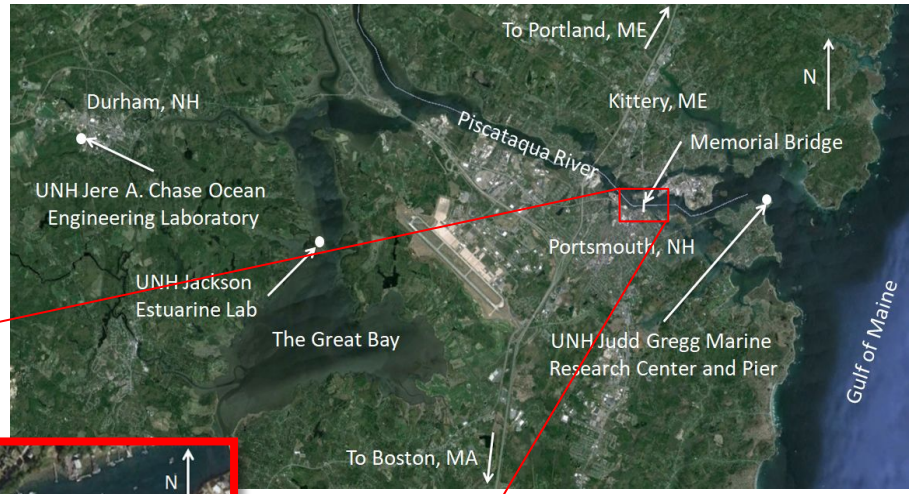
- Enables the testing and improvement of marine energy standards
  - IEC TC-114 Technical Specifications for marine energy conversion systems [1,2]
- Modular and Robust
  - Flanged sections
  - Blades
  - Use readily available materials, eg. Schedule 40/80 steel pipe
- Can accommodate extensive instrumentation
  - In blades and hub
  - Nacelle
  - Tower
- Enables quick deployment and removal
  - UNH-AMEC Turbine Deployment Platform!
  - Incremental Testing



2.5-meter diameter OSTEC turbine

Where is are we deploying the OSTEC turbine?

UNH-AMEC Tidal Energy Test Site in Portsmouth, NH, Great Bay Estuary



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Below: Turbine Deployment Platform (TDP), originally developed as part of the "Living Bridge Project" [3,4]

Design constraints and measurement goals for the OSTEC

- The Turbine Deployment Platform (TDP) at the UNH-AMEC Tidal Energy Test Site gives design/size constraints and the mooring details [3,4]
  - Diameter, hub depth, weight
- Resource assessments informed use of OpenFAST to create an extensive Design Load Case (DLC) [5,6,7]
- Testing the measurement load cases (MLCs) outlined in IEC 62600-3 which have overlap with the Desing Load Cases (DLCs) [2]

DLC Description								Blade Loads				Rotor Loads		
DLC	Turbine State	Test #	TSR	RPM	Mean Current Speed (m/s)	TI (%)	Turbulence Model	Flapwise Bend Moment (N-m)	Edgewise Bend Moment (N-m)	Pitching Moment (N-m)	Blade Thrust (N)	Transverse Off-axis Load (N)	Vertical Off-axis Load (N)	Torque (N-m)
1.1 & 1.3	Normal Operation	1	4.11	80	2.56	7.8	NTM	3807	1050	107	5757	597	1636	3805
		2	2.73	50	2.41	8.1	NTM	2179	984	118	3604	483	1501	3650
		3	5.46	100				3927	759	96	5658	486	1509	2478
		4	Max	150				4459	445	323	5764	384	1399	1231
		5	2.73	50	2.41	11.6	ETM	2287	1099	131	3842	672	1685	4079
		6	5.46	100				4518	969	118	6593	755	1750	3124
		7	Max	150				5222	605	347	6920	598	1575	1735
		8	2.57	50	2.56	7.8	NTM	2212	1042	125	3744	506	1518	3993
		9	5.65	110				4389	791	127	6234	509	1501	2741
		10	Max	150				4968	552	311	6557	435	1415	1590
		11	2.57	50	2.56	11.7	ETM	2328	1167	139	4064	729	1736	4491
		12	5.65	110				5092	1030	157	7322	829	1756	3575
		13	Max	150				5899	764	342	7970	705	1633	2231
		14	2.50	10	0.5	13.8	NTM	81	92	5	143	36	1096	158
		15	2.73	21	1	10.8		357	207	21	607	113	1184	617
		16	2.73	31	1.5	9.4		825	407	47	1391	275	1299	1414
		17	5.46	83	2	8.5		2914	632	85	4341	596	1630	2024
		18	5.46	104	2.5	7.9		4451	929	130	6657	882	1813	2993
4.1	Normal shutdown	1	Rated Torque		2.56	7.8	NTM	4677	1018	121	6705	801	1890	3635
		2	Rated Torque					3095	748	67	4524	461	1481	2349
		3	Rated Torque					4125	1035	110	6109	814	1793	2919
5.1	Emergency shutdown	1	BOP		3.3	NA	Steady	4697	1264	146	6739	0	1066	4811
		2	Highest RPM		3.3	NA	Steady	5220	1264	164	6919	0	1066	4811
		3	Rated Torque		2.56	7.8	NTM	4648	1042	145	6625	801	1890	3784
		4	Rated Torque					3095	748	66	4524	461	1439	2349
		5	Rated Torque					4279	1035	98	6342	1014	1793	2780
6.1	Parked w/ 0° misalignment	1	NA	NA	3.3	NA	Steady	668	244	20	1334	0	1066	988
		2	NA	NA	2.56	7.8	NTM	598	222	20	1215	149	1201	868
	Parked w/ +30° misalignment	3	NA	NA	3.3	NA	Steady	588	371	29	1342	691	1066	1001
		4	NA	NA	2.56	7.8	NTM	565	214	37	1251	266	1234	922
	Parked w/ -30° misalignment	5	NA	NA	3.3	NA	Steady	629	393	31	1433	736	1066	1070
		6	NA	NA	2.56	7.8	NTM	561	375	33	1308	760	1164	977

DLC table for the OSTEC turbine: Neary et al (2024)

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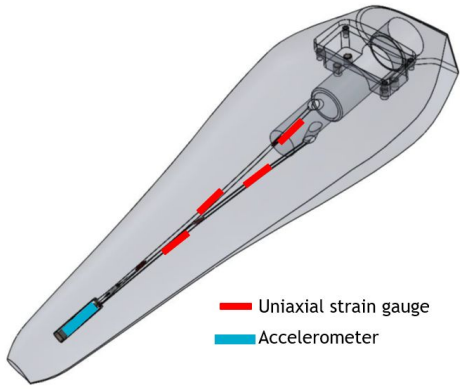
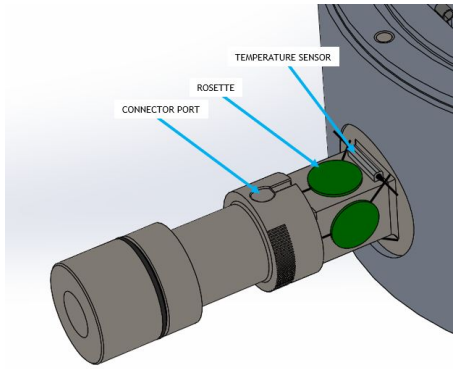
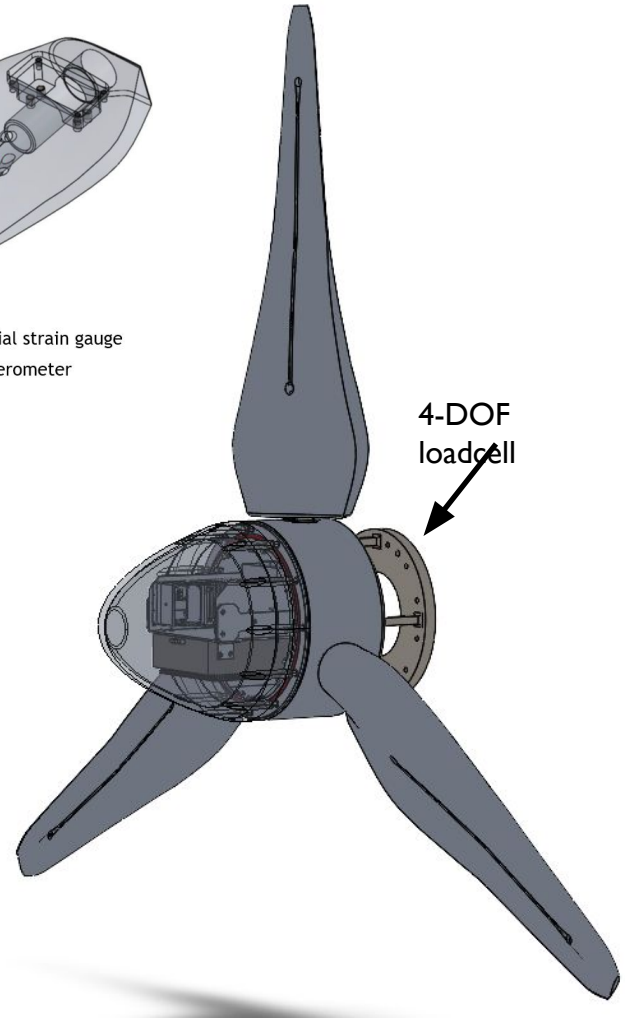
Rotor Design

- 3-bladed rotor, each blade is instrumented with:
  - 4 fiber optic strain gauges (FBG) on front and back surfaces
  - 4 FO rosettes on the rectangular blade root
  - 1 FO accelerometer near the blade tip
  - 1 temperature sensor
- Fiber optic interrogator and DAQ in hub to minimize cable routing to slip ring
- 4-axis loadcell between rotor and shaft to measure key loads for DLCs and MLCs

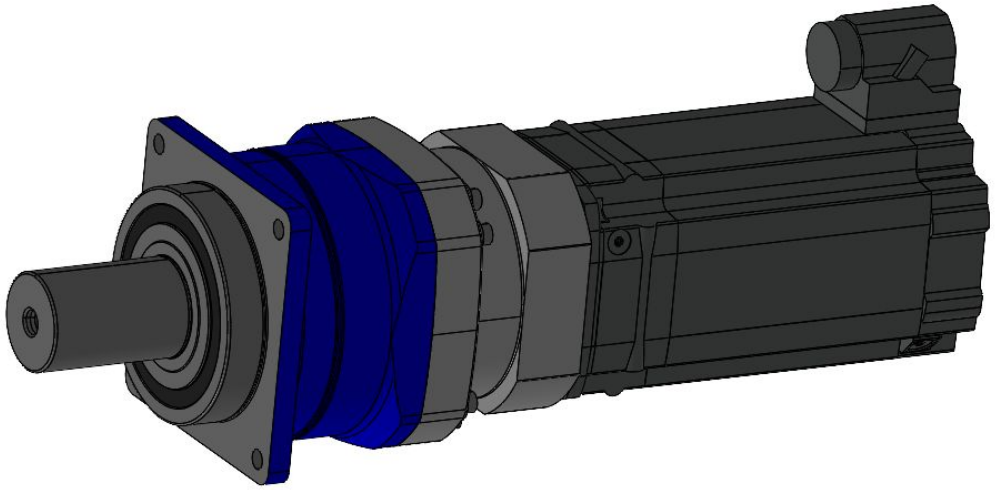




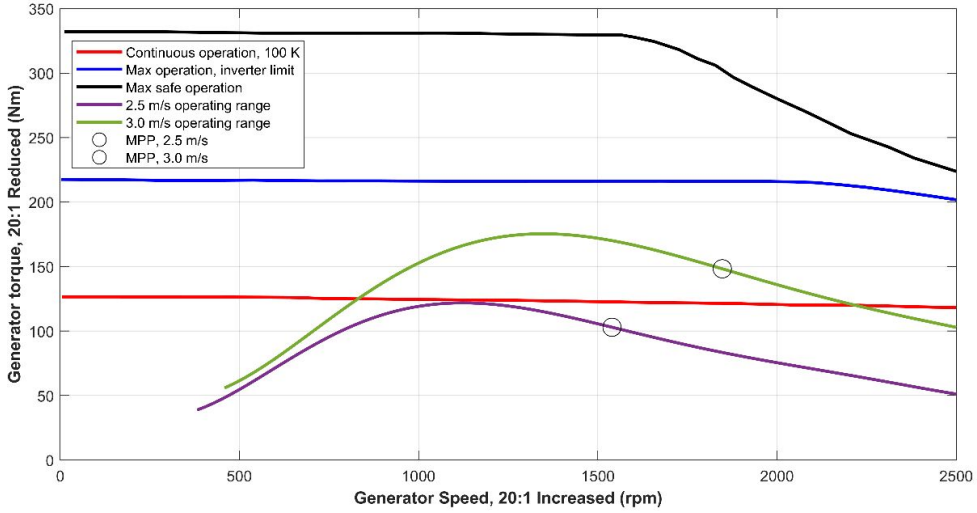


Power Take-off design

- **Siemens PM servomotor**
  - Rated power = 26.2 kW
  - Rated speed = 2000 RPM
  - Fluid cooling system needed to dissipate heat

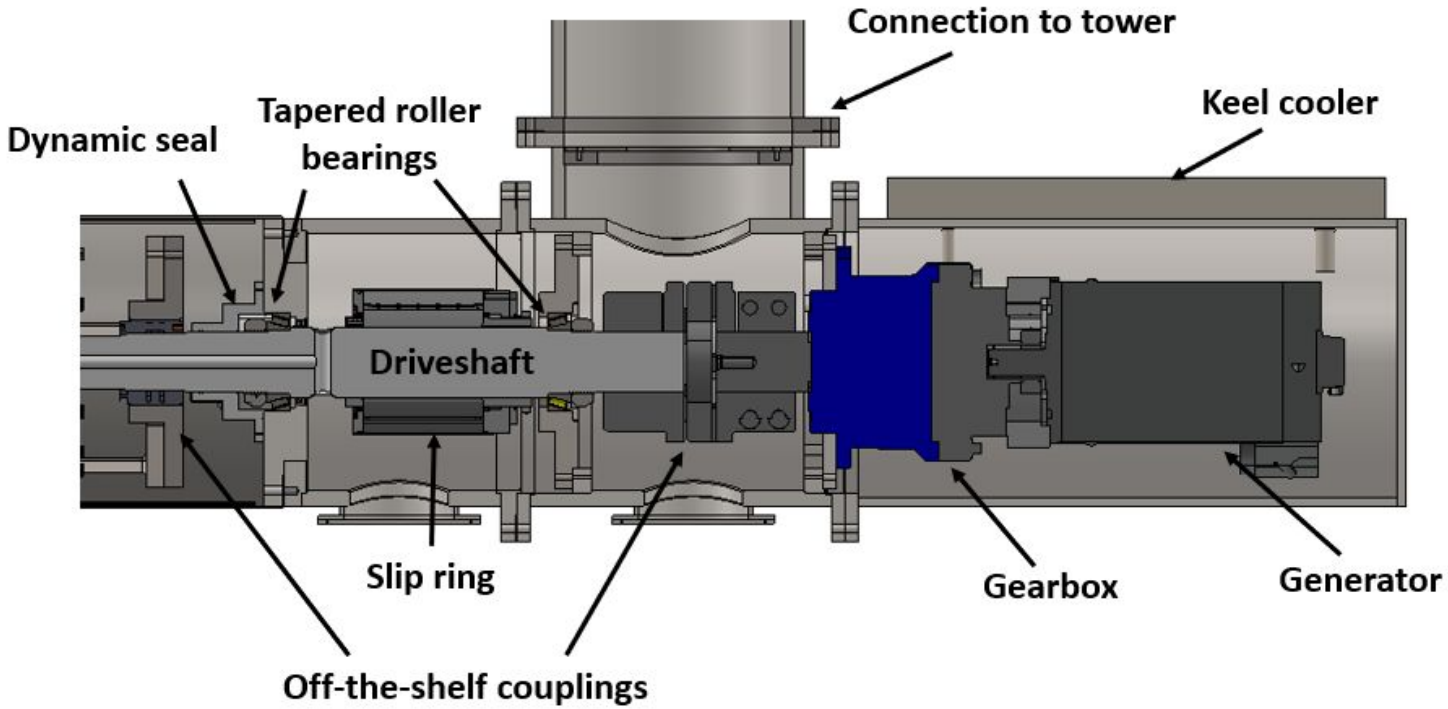


- **Wittenstein SP +240 planetary gearbox**
  - 20:1 gear ratio to align with projected performance envelope
  - Max. torque = 5400 Nm



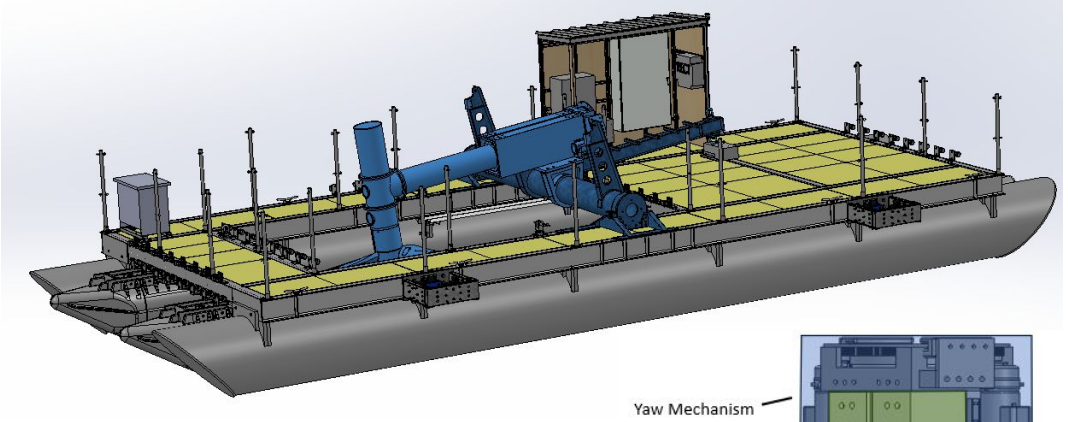
Nacelle design

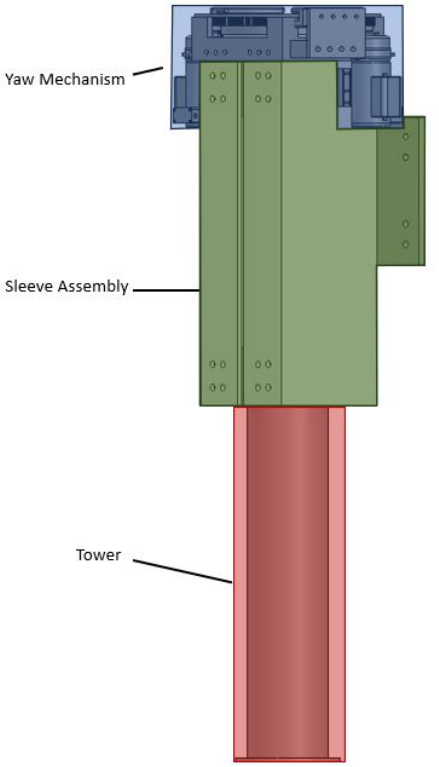
- **Multifunction:**
  - Transmit power from rotor the generator
  - Protective housing for sensitive components
  - Transmit thrust from driveshaft to tower
- **Off-the-shelf parts where possible and keeping machinability in mind when not**



Tower and Yaw Assembly design

- Tower
  - 14” schedule 80 pipe
  - Instrumented with 8 strain rosettes
- Yaw mechanism
  - Allows for yawing the turbine and lockdown in 5°increments with range of +/-30°
  - Designed to rotate 180°to operate in flood tide and reproduce incremental adjustment (for future testing)
- Sleeve Assembly
  - Supports the turbine tower with sleeve bearings
  - Transmit turbine thrust from the tower to the TDP





Instrumentation and Sensors

- Environmental sensors
  - ADCPs, ADVs, WeatherStation, CTD
- Operational sensors
  - 4DOF loadcell, FO blade root and span strain gauges, FO accelerometers, tower foil strain gauges
  - Siemens performance monitoring, low- and high-speed encoders
- Health monitoring sensors
  - Leak detecting cables, temperature sensors, pressure transducer, relative humidity sensor
- Over 100 data streams to manage

IEC 62600-3: Measurement of Mechanical Loads	
Load Quantities:	Blade Root Flapwise Bending Moment (M_bf)
	Blade Root Edgewise Bending Moment (M_be)
	Rotor Torque (M_r)
	Base of Tubular Column Normal Moment
	Base of Tubular Column Lateral Moment
	PTO Absolute and Relative Positions
	Rotor Tilt Moment (M_tilt)
	Rotor Yaw Moment (M_yaw)
Operation Quantities:	PTO Power output
	Generator Speed
	Rotor Speed
	Yaw Misalignment
	Rotor Azimuth Angle
	Blade Pitch Position
	Pitch Speed
	Operational State of Control System
	Control System input Data and status
	Brake Status
	Brake Moment/pressure
Oceanographic Quantities:	Current Speed
	Current Direction
	Water Temperature
	Current Turbulence Intensity
	Current Vertical Distribution
	Surface Elevation and Water Depth
	Ice Accretion Potential
	Wind Speed
	Wind Direction
	Air Temerature
	Air Humidity
	Atmospheric Pressure

IEC 62600-200: Electricity Producing Tidal Energy Converter: Power Performance Assessment	
Electrical Quantities:	PTO output Voltage
	PTO output Current
Operation Quantities:	Operational State of Control System
	Control System input Data and status
Oceanographic Quantities:	Current Speed
	Current Direction
	Water Temperature
	Current Turbulence Intensity
	Current Vertical Distribution
	Surface Elevation and Water Depth
	Waves

IEC 62600-202: Scale testing of tidal stream energy systems (Based on Stage 2 Testing)	
Performance Quantities:	Torque
	Power
	Thrust
	Blade Flapwise Bending Moment
	Blade Edgewise Bending Moment
	Rotational Position
	Rotational Velocity
	Out-of-plane Bending
Motion and other Load Quantities:	Platform Motion
	Platform Loads
	Cross-sectional Loads
	Mooring Loads
	Modal Frequencies
Oceanographic Quantities:	Current Speed (point source)
	Current Speed (shear profile)
	Water Temperature
	Current Turbulence Intensity
	salinity/conductivity
	Waves

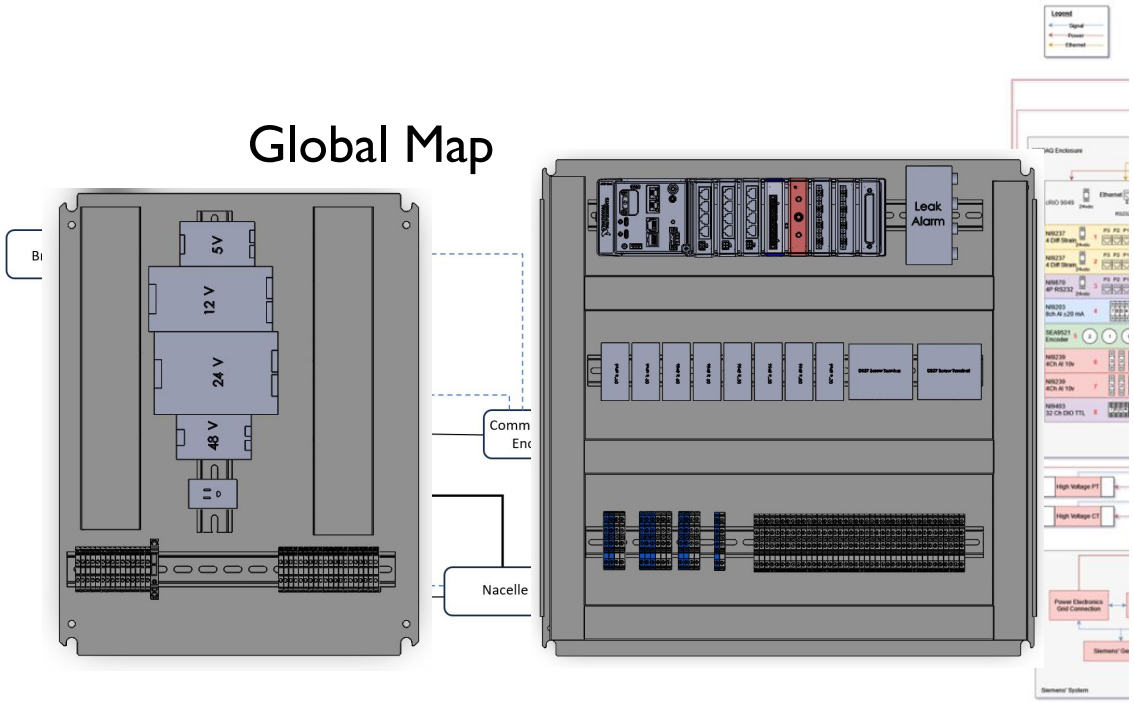
Additional Measurements	
Mechanical Load Quantities:	Blade Strain
	Blade Modal Frequencies
	Platform Guide Post Loads
	Platform Position on Guide Posts
Electrical PTO Quantities:	Active/Reactive Power
	Active/Reactive Current
	Active/Reactive Voltage
System Health Quantities:	Turbine Leaks
	Turbine Humidity
	Turbine Temperature
	Turbine Gauge Pressure
	Generator Coolant Flow
	Generator Temperature

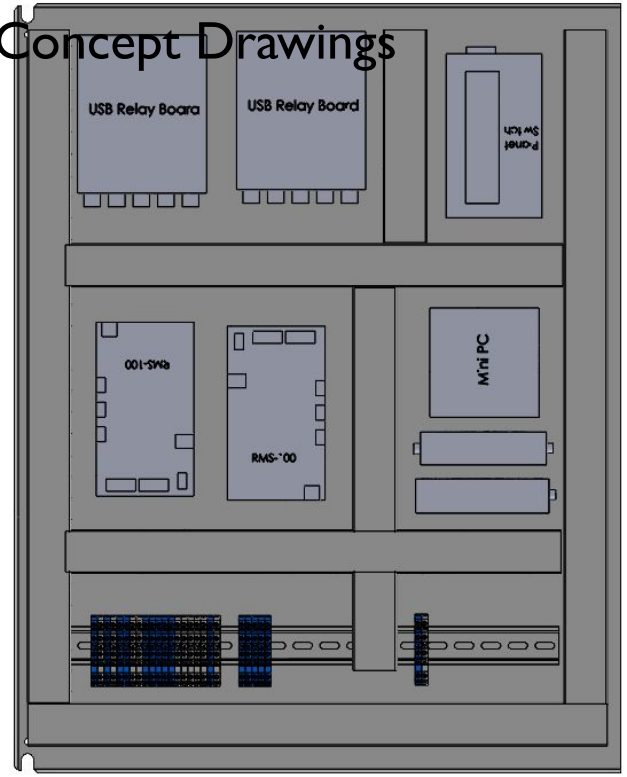
Data Acquisition System (DAQ) design

- NREL's Modular Ocean Data Acquisition System (MODAQ)
  - Collect, synchronize, and control over 100 data streams

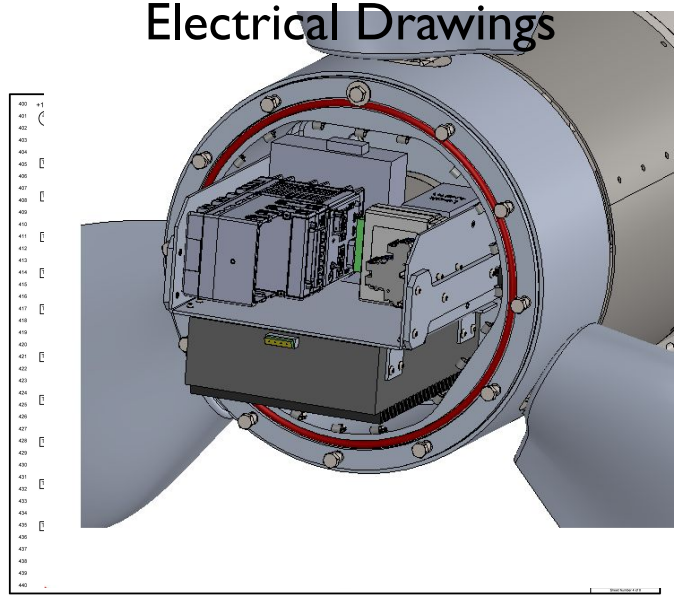
Concept Drawings

Global Map





Electrical Drawings



Cost Summary of OSTEC turbine (to date)

- **Mechanical parts**
  - Rotor ~$56k
  - Power Conversion system ~$40k
  - Nacelle ~$94k
  - Tower and Yaw Assembly ~$75k

Subtotal of Mechanical parts = $275k

- **Sensors and Acquisition Equipment**
  - Instrumentation and DAQ ~$150k

Total parts cost of the OSTEC turbine is approximately $425k

Unique Challenges and Next Steps

- **Alignment and tolerance stack-up between parts in a complicated system**
  - Driveshaft requires high degree of alignment spanning over multiple parts
- **Design of DAQ system**
  - Global level to enclosure level
- **High degree of system complexity**
  - All parts (both sensors and mechanical components) need to function independently, as well in its subsystem, and the greater system
- **For more details on system development and integration, stay tuned for Parviz Sedigh's presentation!**

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