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System Integration of an Instrumented Open-Source Tidal Energy Converter (OSTEC) Testbed

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Abstract

System integration involves the combination of various subsystems, assemblies, sub-assemblies, components, and parts into a unified, cohesive system. Herein, we detail the system hierarchy, workflow and tasks to integrate and test subsystems, assemblies, subassemblies and components of an open-source tidal energy converter system, which includes rotor, blades, Power takeoff, turbine yaw mechanism subassemblies as well as data acquisition subsystem and turbine deployment platform. The turbine system includes a nacelle, a 2.5 m diameter rotor with hub and blades, motor/generator, gearbox, tower with a yaw drive, many sensors, and power/data cables. The turbine system integration is a critical task prior to subsystems testing and deployment. Blades are machined, equipped with sensors, and calibrated before assembly. Motor control and instrumentation will be integrated into a UNH-built variant of the NREL-MODAQ. The OSTEC testbed will undergo several stages of calibration and deployment readiness verification at the UNH/AMEC dry testing facilities prior to being integrated onto the Living Bridge open water deployment platform for long term testing at the Memorial bridge test site. With the system integration, the goal is to provide a unified system that comprises different subsystems, assemblies and subassemblies that can provide data on inflow conditions, power performance, mechanical loads, and health monitoring of the overall system. This work will provide an update on the Instrumented Tidal Turbine Testbed's system integration.

Keywords: System Integration; Marine Turbine; Tidal Energy; Renewable Energy; Energy Conversion

1. Introduction

Tidal currents, or tidal streams, are horizontal water movements driven by the changing gravitational pull of the Earth, Moon, and Sun. These currents offer a significant, untapped energy source [1], that can be harnessed through tidal energy converters (TECs). TECs generate clean, renewable power that are environmentally friendly and can cover a large demand. Most studies in this field focus on resource assessment [2], resource forecasting [3], design concepts,

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small-scale models, and operational devices. Tidal turbine, a type of TECs which converts the kinetic energy of tidal current into electricity, is been designed and is in system integration phase. Effective system integration which is the process of combining and coordinating a turbine's components, parts, subassemblies, and assemblies, is a crucial phase for creating a functional and operable system.

This project aims to design, build, and deploy an instrumented marine turbine in a real tidal environment. The Open-Source Tidal Energy Converter (OSTEC) will serve as an R&D testbed [4]. With a 2.5-meter rotor and 25kW rated power, this axial flow tidal turbine will produce open-source data on recommended best practices given in international standards, including the International Electrotechnical Commission's (IEC) technical specification on design of marine energy systems (IEC TS 62600-2), mechanical load measurements (IEC TS 62600-3), power performance assessment (IEC TS 62600-200), tidal resource characterization and assessment (IEC TS 62600-201), and scale testing of tidal energy converters (IEC TS 62600-202) as well as enabling comprehensive model verification and validation [5] for digital twining and numerical models .

This extended abstract outlines tidal turbine subsystem integration and details the process for building the OSTEC Testbed [4]. System integration involves different systems, subsystems, assemblies, and subassemblies of components & parts where they go through the process of testing, integration, operation, and pre-deployment preparations. Several tasks will be performed both individually and in parallel during system integration, and this paper aims to provide a methodological way for the hierarchy of system integration of the OSTEC Testbed. A detailed system hierarchy and break down as well as testing and integration process will be provided here.

Nomenclature			
UNH	University of New Hampshire	PTO	Power Takeoff
AMEC	Atlantic Marine Energy Center	DAQ	Data Acquisition
SNL	Sandia National Laboratories	TDP	Turbine Deployment Platform
NREL	National Renewable Energy Laboratory	FEA	Finite Element Analysis
PNNL	Pacific Northwest National Laboratory	ADCP	Acoustic Doppler Current Profiler
TEC	Tidal Energy Converter	ADV	Acoustic Doppler Velocimeter
MODAQ	Modular Ocean Data Acquisition	PTP	Precision Time Protocol
		VPN	Virtual Private Network

2. System Components and Integration

At UNH/AMEC in partnership with Sandia National Laboratories (SNL), National Renewable Energy Laboratory (NREL), and Pacific Northeast National Laboratories (PNNL), system integration of an axial flow tidal turbine is developing. The OSTEC system comprises three main subsystems illustrated in figure 1: (a) a three-bladed axial flow hydrokinetic turbine for power generation, (b) a sensor-instrumented data acquisition (DAQ) system for measuring inflow conditions, power performance, mechanical loads, and health monitoring of turbine components, and (c) a turbine deployment platform (TDP) located on a real tidal flow test site.

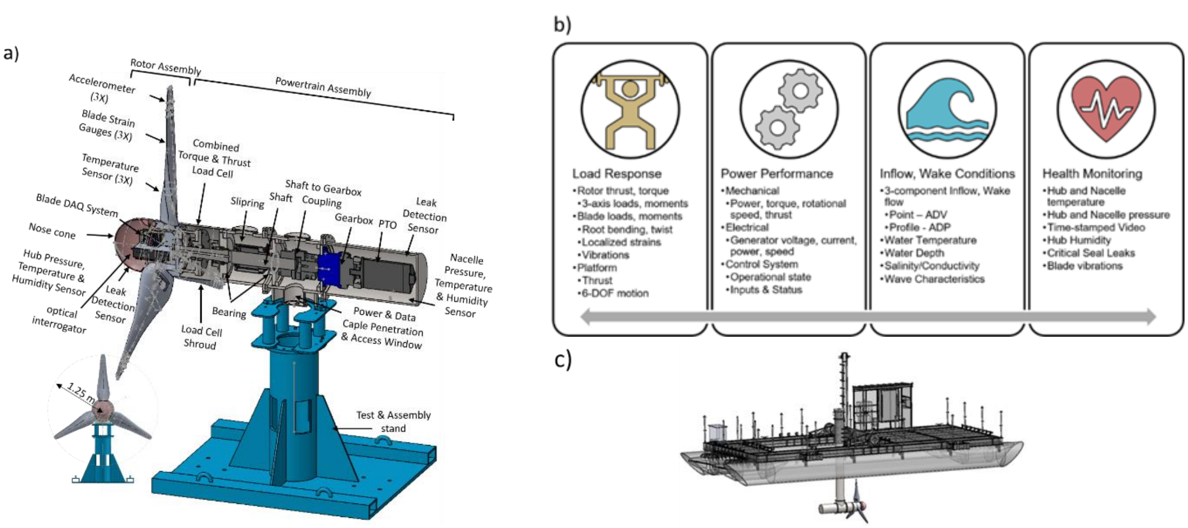

Fig. 1. (a) OSTEC Turbine breakdown of subassemblies, components & hierarchy. (b) Measurement purposes & list of sensors [4]. (c) Render of TDP & OSTEC Turbine

2.1. System Hierarchy

The hydrokinetic turbine subsystem [7] is divided into three main subassemblies: the nacelle [8] with its subassemblies, the rotor (hub, nosecone, and blades), and the tower with a yaw drive. The assembly sequence was carefully planned during the design process. The nacelle houses a synchronized motor/generator, a gearbox, drive shaft and bearings, a slip ring for power and data transfer to/from the hub, seals, various health monitoring sensors, and penetrations for power and data cables. The 2.5-meter diameter rotor includes a hub, three instrumented blades each measuring 1.5 meter in length, an optical interrogator for fiber optic strain gauges, a data acquisition system for sensors and blades, blade-hub attachments, and seals. Fig. 1. (a) shows a cross-sectional view of the nacelle and rotor, including the hub and blades, as well as the arrangement of the nacelle components.

2.2. System Integration

System integration involves the combination of various subsystems, assemblies, sub-assemblies, components, and parts into a unified, cohesive system [6]. For the OSTEC instrumented turbine, the primary objective is to methodically coordinate the testing, connection, and assembly of each individual component, sub-assembly, and the entire system. This process ensures that each element functions correctly on its own and seamlessly with the other elements, achieving the specified design basis functionalities and design objectives.

The integration process is carefully planned to verify and validate the performance at multiple levels, ensuring reliability and efficiency. The flow chart in Fig. 2, demonstrates the sequence and interdependencies of the testing, assembly, and system integration activities planned for the OSTEC turbine, highlighting the organized approach required to bring the system together successfully.

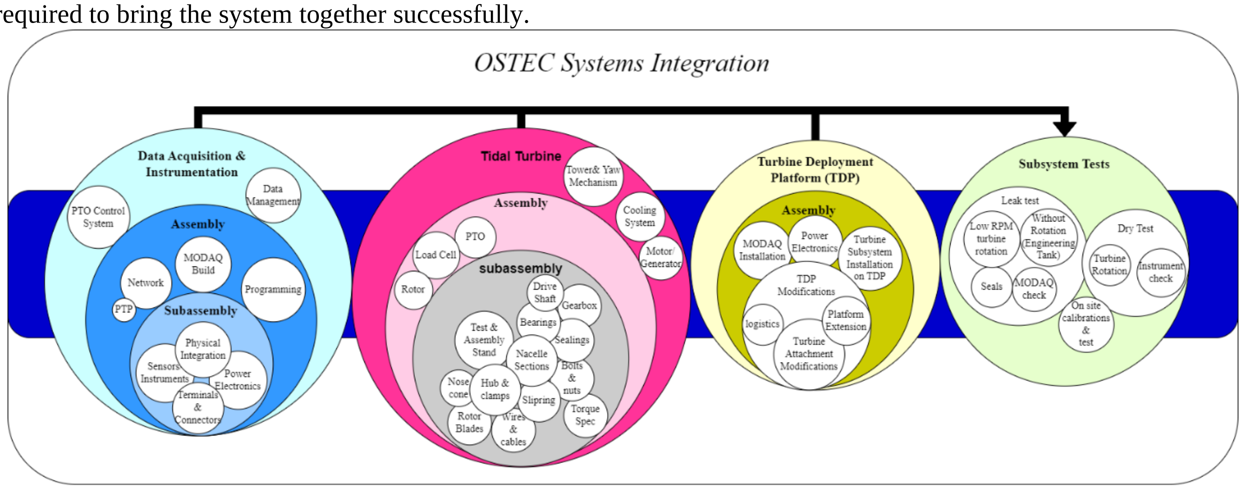

Fig. 2. Overview of OSTEC System Integration

Fig. 2, illustrates that several tasks must be performed both individually and in parallel during the system integration process. Many of these tasks either overlap or follow a specific sequence. For instance, developing the Power Takeoff (PTO) control system and building the DAQ system occur simultaneously, while testing instruments and building MODAQ are sequential tasks.

3. Methodology

Referring to Fig. 2, each task in a system integration process plays a crucial role in ensuring the seamless assembly and functionality of the OSTEC testbed. The following subsections provide an in-depth explanation of each task, detailing the specific steps and methodologies involved.

These comprehensive descriptions, along with Fig 2, aim to clearly illustrate the significance and sophistication of the system integration process for the OSTEC turbine. By outlining each task in detail, we emphasize the thorough planning and coordination required to achieve a fully functional and efficient turbine system. This section will demonstrate how each component and sub-assembly is systematically integrated to meet the design objectives and operational standards.

3.1. PTO Control and Instrumentation

One of the primary objectives of this project is to provide a comprehensive open-source dataset for power performance, mechanical and design loads, and tidal inflow conditions of an axial flow tidal turbine operating in a real tidal flow environment. To achieve this, several sensors, instruments, and devices will be implemented on the turbine subsystem to measure the necessary parameters. Fig. 1(b) categorizes these parameters, reflecting the number of sensors and instruments that will be utilized. From this figure, one can appreciate the extensive set of data that will be available once the axial flow tidal turbine is deployed in a real tidal flow environment.

A customized data management strategy will be implemented using a Data Acquisition (DAQ) system specifically designed to meet the OSTEC turbine's requirements. This DAQ system is essential for recording key parameters and performance metrics during test and operation, enabling detailed analysis, monitoring, control, and other applications. Fig. 3 depicts the DAQ system scheme planned for use with the OSTEC turbine.

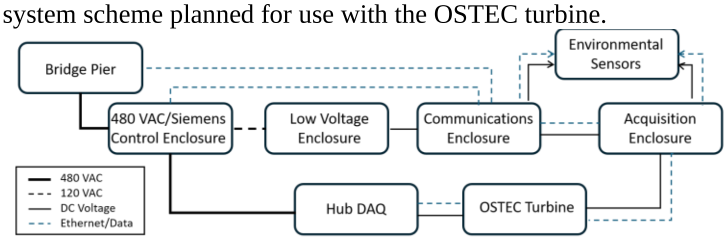

Fig. 3. DAQ system scheme

Additionally, a synchronized motor/generator is depicted in Figure 4(a). Commissioning the motor and its control components is another crucial task performed during the system integration process. By defining various control parameters, the motor will be spin at low speed to ensure the PTO subsystem's full functionality and to determine the parameters needed for integration with the DAQ.

(a) (b)

Fig. 4. (a) Power takeoff and DAQ; (b) Hub-DAQ

The SNL smart sensor marine hydrokinetic family 1 (MHKF1) blades [2] were tested at Sandia's Applied Combined Mechanical Environments (ACME) laboratory by equipping the blades with fiber optic strain gauges sensors, as shown in Fig. 5. This process requires a high degree of precision due to the sensitivity and fragility of the strain gauges. When installing the gauges in the grooves made on the blades, the grooves need to be filled with epoxy to provide sealing and then sanded down to maintain the blade profile. The factory calibrated strain gauges were tested and verified prior to assembly of the rotor, integrated with the DAQ system.

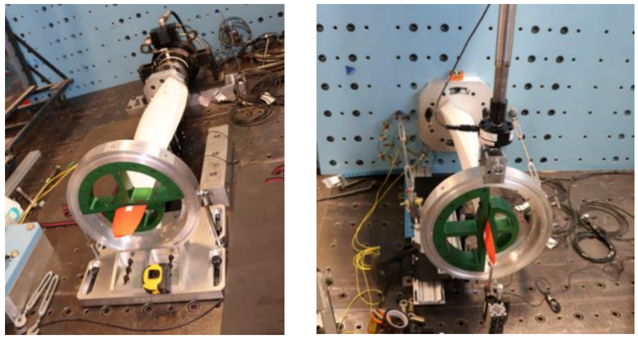

Figure. 5. Bending moment and torsion testing of blades

3.2. Data Acquisition

The Modular Ocean Data Acquisition (MODAQ) system, originally developed by NREL [9], will be the primary DAQ for the OSTEC Testbed, with a variant built by UNH/AMEC for the tidal energy test site. MODAQ will also monitor turbine health, link with the PTO for data gathering, and perform control tasks like turbine setpoint adjustments. By being accessible via VPN, it will use cloud capabilities to transfer data for automated analysis. Precision time protocol (PTP) will synchronize clocks across the DAQ network, ensuring sub-microsecond accuracy with the help of a GPS receiver.

The UNH-MODAQ, as a sub-system, will undergo turbine system integration. This involves power-electronics and physical build phases. During the power-electronic phase, sensors and components are individually tested, then physically integrated into the DAQ system. NREL-developed programs for each instrument are deployed and thoroughly tested. Sub-system integrity checks follow to ensure readiness for higher-level system integration.

The UNH-MODAQ build for the OSTEC Testbed consists of four enclosures: a 480 VAC power cabinet, a power converter console, a communication enclosure, and the DAQ enclosure. The power cabinet regulates electricity production and consumption at the test site, while the power console converts 120 VAC to necessary DC voltages. The communication enclosure holds network components and relays, and the DAQ enclosure contains the system's processors. A smaller DAQ system at the rotor hub, as shown in Fig 4(b), will manage sensors and instruments on the turbine rotor. These include fiber optic strain gauges, pressure and temperature sensors, humidity sensors, and a leak detection system. Data from the hub DAQ system will be transferred to the MODAQ on the TDP via a slipring.

3.3. Mechanical integration

Mechanical integration is a crucial phase within the system integration process. During this phase, all finalized designs are sent to fabricators and machine shops for manufacturing or to be ordered, as necessary. This step is critical as the tidal turbine subsystem will be submerged in water and must meet specific tolerances for seals and other sections.

Moreover, coating and protecting mechanical parts, especially those exposed to saltwater, is essential. Various protection methods were analyzed, and the most suitable one for the project was selected. For instance, the hydrokinetic blades, hub, and nose cone, as shown in Fig.6, were protected with Cerakote, a ceramic coating technology known for its enhanced resistance against corrosion, scratches, and general wear and tear. Additionally, nacelle, tower and other parts of the turbine is being galvanized in term of components protection against marine environmental conditions.

Fig. 6. Coating of the turbine parts

A custom-built test stand [6] as shown in fig. 7(a) provides a safe, reliable, and efficient platform for system integration. This work platform is essential for holding all parts and components during assembly, subassembly, systems integration, and tests of turbine, where each mechanical assembly and instrumental subsystems meets each other, and they were independently tested to ensure they meet design specifications while they function reliably.

Fig. 7. a) Fabricated test stand b) tower and yaw mechanism

One of the project's goals is to deploy and recover the turbine under various flow conditions, allowing for safe and effective yaw adjustment during testing. A Turbine Yaw Mechanism (TYM) was designed. Fig. 7 (b) shows the proposed TYM, with yaw drives mounted above the waterline. The tower is constructed using a 14" diameter schedule 80 steel pipe, firmly fixed within a mounting bracket that connects to the pitching mechanism, as shown in Figure 3. The yaw adjustment can be made continuously and locked in 5-degree increments, ranging from -30 to +30 degrees in relation to the principal long axis of the platform, using a motor.

To manage the excess heat generated by the generator during turbine operation, a liquid heat exchange device is integrated into the PTO assembly of the turbine subsystem. This involves assembling and testing hoses, pipes, valves, the coolant pump, and the cooling subsystem, all of which are integrated into the aft nacelle section of the turbine.

4. System Testing and Deployment

Many tests like functionality test, operability test and integrity test need to be performed stage by stage during system integration process. This will help to make sure the systems assemblies and subassemblies are integrated correctly, and they are able to function/communicate as a whole unit in an assembly or subsystem level as it needed. Also, this testing process ensures that all the subsystems and assemblies are ready to be integrated and unified for the high-level system that is aimed to be deploy. The following will provide more detail of the tests that will be performed during the OSTEC Testbed's system integration.

4.1. SNL fiber optic sensor (FOS) static blade tests

The FOS sensor system for each of the three SNL smart sensor marine hydrokinetic family 1 (MHKF1) blades were installed, tested and verified at Sandia's ACME laboratory, including the embedded uniaxial FOS gauges along the pressure and suction surfaces of each of the three blades (e.g., Fig. 8a) and the novel fiber optic rosette strain measurement system mounted on a cuboid section to decouple strain measurements via four distinct orthogonal surfaces, enabling precise fiber optic strain measurements on a simple structural element that can be easily characterized and modeled to compute pitch moment, and flapwise and edgewise root bending moments [2].

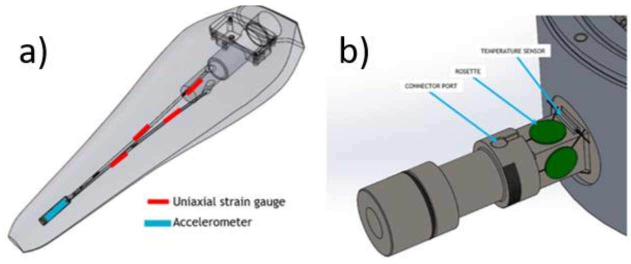

Fig 8. (a) SNL smart-sensor blade with uniaxial fiber optic strain (FOS) gauges and accelerometer; (b) SNL's precision fiber optic rosette strain measurement system mounted on stainless steel cuboid.

4.2. Dry & Leak Test

Dry test refers to tests that assess the mechanical behavior of the turbine components, such as the structural integrity of the rotor and PTO, as well as its instrumentation without involving the actual tidal flow around the turbine. Once the turbine subsystem integrations are completed, the turbine will be mounted on the test stand in an inverted position for a dry test as shown in Fig. 1 a, during which it will be rotated via the synchronous motor through its full operational envelope to check for its mechanical and instrumental integrity and ensure proper functioning of all components and subassemblies.

Following the dry test, a pressurization/vacuum leak test of the nacelle and hub assembly will be performed in the laboratory by creating the same pressure difference as during the in-water deployment, but with air on both the outside and inside. This will ensure use that our turbine systems' components are perfectly sealed against any water penetration. A vacuum will be created inside the nacelle and hub to a gage pressure comparable to the approximate hydrostatic pressure the turbine nacelle and hub will experience while deployed, approximately 0.2 bar. This is considered a more rigorous leak test than testing under water, due to the small size of air or inert gas (N2) molecules. Pressure will be monitored with pressure sensors. Once the confidence of turbine integrity achieved, the entire turbine subsystem will be transported to UNH research pier for a before deployment in water test and checks.

4.3. Preparation for Deployment

The Great Bay Estuarine (GBE) system is one of the most energetic tidally driven systems on the East Coast of the United States. A the UNH\AMEC test site. The UNH\AMEC tidal energy test site is located at the Memorial Bridge crossing the Piscataqua River in Portsmouth, NH on the GBE system. At this test site, tidal current speeds over 2.8 m/s have been observed with 2-minute ensemble averaged ADCP measurements and instantaneous, local current speeds over 3.3 m/s with 16 Hz ADV measurements [10]. Fig. 1 (c) shows a render of the designed turbine attached to UNH Turbine Deployment Platform and fig. 9 shows the UNH Turbine Deployment Platform (TDP) connected to the bridge pier at the test site.

Before turbine deployment, the TDP will be detached from the bridge pier at UNH-AMEC test site and transported to the UNH Pire Facility (Judd Gregg Marine Research Center) located at Newcastle, NH for significant modifications and maintenance. The TDP, originally developed as part of the Living Bridge project [11], needs updates to meet OSTEC requirements. These modifications include structural changes for turbine attachment, installation of a new 480 VAC power enclosure and its environmental shed, extension of the platform base to enhance buoyancy and eliminate pier shear flow turbulence effect on the platform moon pool (test section), and ultimately, the installation of the OSTEC testbed on the platform for real deployment. Moreover, check of instrumentation and some in- situ processes like alignments & adjustments will happen during this time. The turbine subsystem will slowly be operated to safely check integrity of dynamic seals. After in water tests and systems check, the turbine will be secured on the deployment platform, it to be transferred to the test site for the actual deployment.

Fig. 9. TDP and UNH test site

5. Summary & Conclusion

System integration for an axial flow tidal turbine involves assembling and ensuring the proper functioning of mechanical, instrumental, and electronic components that have been pre-designed, prepared, and tested. These components will be housed in the nacelle and rotor, and the process will occur on a custom-built test stand, allowing the turbine to be rotated with a motor. A leak test will confirm waterproof connections, and the UNH-built MODAQ system will handle all measurements during testing and deployment. The deployment is planned for the UNH/AMEC tidal energy test site at Memorial Bridge, Piscataqua River in Portsmouth, NH. System integration process aims to streamline the system's integrity, reliability, efficiency, operation, and lifecycle by seamlessly integrating various components, controls, and infrastructure, requiring expertise in mechanical and electrical engineering, control systems, and project management. A lot of lessons will be learned during and after system integration phase of the OSTEC Testbed. The OSTEC testbed represents a significant advancement in tidal energy converter technology. Its integration and deployment will provide valuable data for further research and development in the field of marine renewable energy and helping the technology in this field make more progress by testing, demonstration and improvement of recommended best practices given in international standards, including the International Electrotechnical Commission’s technical specification on design of marine energy systems (IEC TS 62600-2), mechanical load measurements (IEC TS 62600-3), power performance assessment (IEC TS 62600-200), tidal resource characterization and assessment (IEC TS 62600-201), and scale testing of tidal energy converters (IEC TS 62600-202).

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