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ReDAPT Deliverable MC 9.5 – Recommendations for the Testing of Tidal Turbines

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1 MC 9.5 – TITLE AND ACCEPTANCE CRITERIA

1.1 Title of MC 9.5 Work-Package

Title: *"Recommendations for Specification and Testing of Tidal Turbine"*

NB: For the purpose of clarity this work-package has been split into 2 separate stand-alone reports:

- TG-RE-000-1028 Recommendations for the Specification of Tidal Turbines
- TG-RE-000-1036 Recommendations for the Testing of Tidal Turbines

1.2 Acceptance Criteria of MC 9.5 Work-Package

The following section is copied from the ETI ReDAPT programme acceptance criterion as stated against work package MC 9.5:

" Issued report containing complete list of parameters, units of measurement, formats and calculations required to fully specify a tidal turbine (i.e. such that a product can be assessed or selected) and a full list of assembly, pre-delivery and commissioning tests that a developer can use as their test programme."

Whilst a complete list of parameters required to fully define a tidal turbine is provided within report TG-RE-000-1028 ("Recommendations for the Specification of Tidal Turbines"), report TG-RE-000-1036 aims to address the remainder of the acceptance criterion by delivering a generic list of assembly, pre-delivery and commissioning checks that a developer could use as the basis for a test programme.

2 ACRONYMS

A	Ampere
ACH	Anti-Condensation Heater
ADCP	Acoustic Doppler Current Profiler
CDB	Central Distribution Board
CMS	Cable Management System
DC	Direct Current
EHM	Equipment Health Monitoring
ELV	Extra Low Voltage (i.e. 24v)
ETI	Energy Technologies Institute
FAT	Factory Acceptance Test
FC	Frequency Converter
GPS	Global Positioning System
HMI	Human Machine Interface
HPU	Hydraulic Power Unit
HS	High Speed
HV	High Voltage (i.e. > 1000v)
I/O	Input / Output
IP	Internet Protocol (Address)

LS	Low Speed
LV	Low Voltage (i.e. 50v < v < 1000v)
PC	Personal Computer
PLC	Programmable Logic Controller
ReDAPT	Reliable Data Acquisition Platform for Tidal
RF	Radio Frequency
ROV	Remotely Operated Vehicle
RPM	Revolutions per Minute
SCADA	Supervisory Control and Data Acquisition
Tb	Terra-byte
UPS	Uninterruptible Power Supply
V	Voltage
VSDL	Video Screen Description Language
°C	Degrees Centigrade
Ω	Ohm

3 ASSUMPTIONS

In generating this document, the following assumptions have been made:

a. The following divisions are assumed in defining the "*Assembly*" (or "Sub-System"), "*Pre-Delivery*" (or "Whole Turbine System Level") and "*Commissioning*" (or "Deployed Commissioning") stages of the "Customer delivery" process:

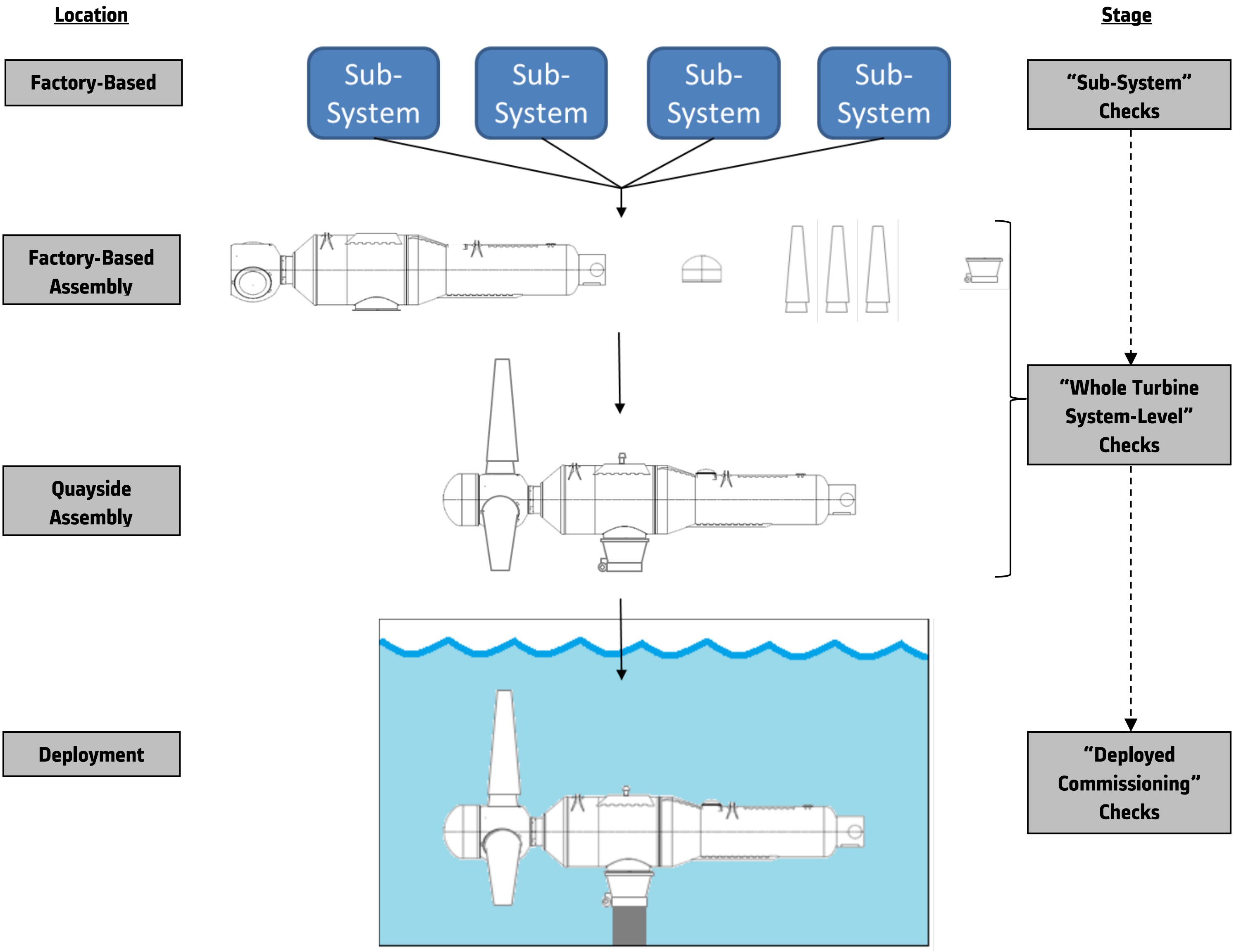

Figure 1: Definition of Stages for "Assembly", "Pre-Delivery" and "Commissioning" Checks

b. All design validation testing has been successfully completed in the "pre-productionisation" phase of the development process, and as such none of the testing or checks suggested within this document constitutes design validation work.
c. In line with (b), the demonstration of a power curve is deemed encompassed within the design validation phase of a turbines development, hence is not included within the deployed commissioning phase of this report. In addition, the demonstration of a power curve against every production turbine would require the use of sea-bed mounted ADCPs at each location to provide independent confirmation of flow speeds. Hence such a demonstration at an "individual turbine level" becomes impractical, however it is expected that (in production) a power curve would be guaranteed by the manufacturer.
d. In line with (b), all testing and checks suggested within this document assume a level of maturity in relation to applicable manufacturing and assembly processes and techniques suitable for large-scale production (and have been validated as such).
e. All testing and checks recommended within this document are commensurate with "early series" production tidal turbines.
f. In line with (a), an assumption is made that all sub-system and whole-turbine system level "pre-delivery" checks and testing are performed "dry" (i.e. no requirement for either dunk-tank testing or quay-side water-trials) unless otherwise stated.
g. In line with (a), an assumption is made that all deployed commissioning checks and testing is preformed "wet" (i.e. either during initial dunk, during towing or during deployment / first energisation of the turbine when fixed to the support structure).
h. An assumption is made that all suggested equipment to perform the checks and testing contained within this document is available as required.
i. In line with (a), an assumption is made that for the deployed commissioning phase of testing, either a "dummy tower-top" support structure or the final position support structure is available for turbine commissioning purposes.
j. An assumption is made that the sealing of all potential leakage paths, trim / ballast checks, etc has been completed as part of the design validation process in developing the turbine to a maturity level commensurate with production.
k. In specifying the testing requirements within this document, an assumption is made that the architecture of the "generic" turbine against which developers would apply this document is similar to the 1MW ReDAPT machine (see figures 2 and 3) – where architecture or design philosophy differs significantly from this reference machine the testing as suggested within this document may no longer be valid.
l. No specialist equipment is necessary to perform any of the Deployed Commissioning Checks (ref. section 6), as subsequent to a successful commissioning phase the assumption is made that the turbine would pass directly into operation.
m. An assumption is made that grid compliance for a specific type of turbine would be demonstrated at a development validation level with subsequent production-phase sub-system factory acceptance tests (FATs) ensuring compliance to that validated design – hence, grid compliance is assumed for production turbines.
n. It is assumed that a list of all parts and equipment, including references to the relevant drawings, which define the proposed type design of turbine has been established prior to production, and that major components which are able to be changed independently either during pre-deployment trials or in-service (e.g. blades, pitch-system, gearbox, shafts, generator, frequency converter, etc.) have suitable means of identification to ensure traceability.
o. In line with (n), it is assumed that an appropriate Configuration Change Management process is in place which captures the following information (as a minimum):
    - turbine serial type and serial number
    - all major component serial numbers
    - software version numbers

   In addition, this change management process should capture any discrepancies between the declared type configuration and that of the turbine being commissioned. It should also maintain a list of all service items which may have been swapped out during the commissioning process.

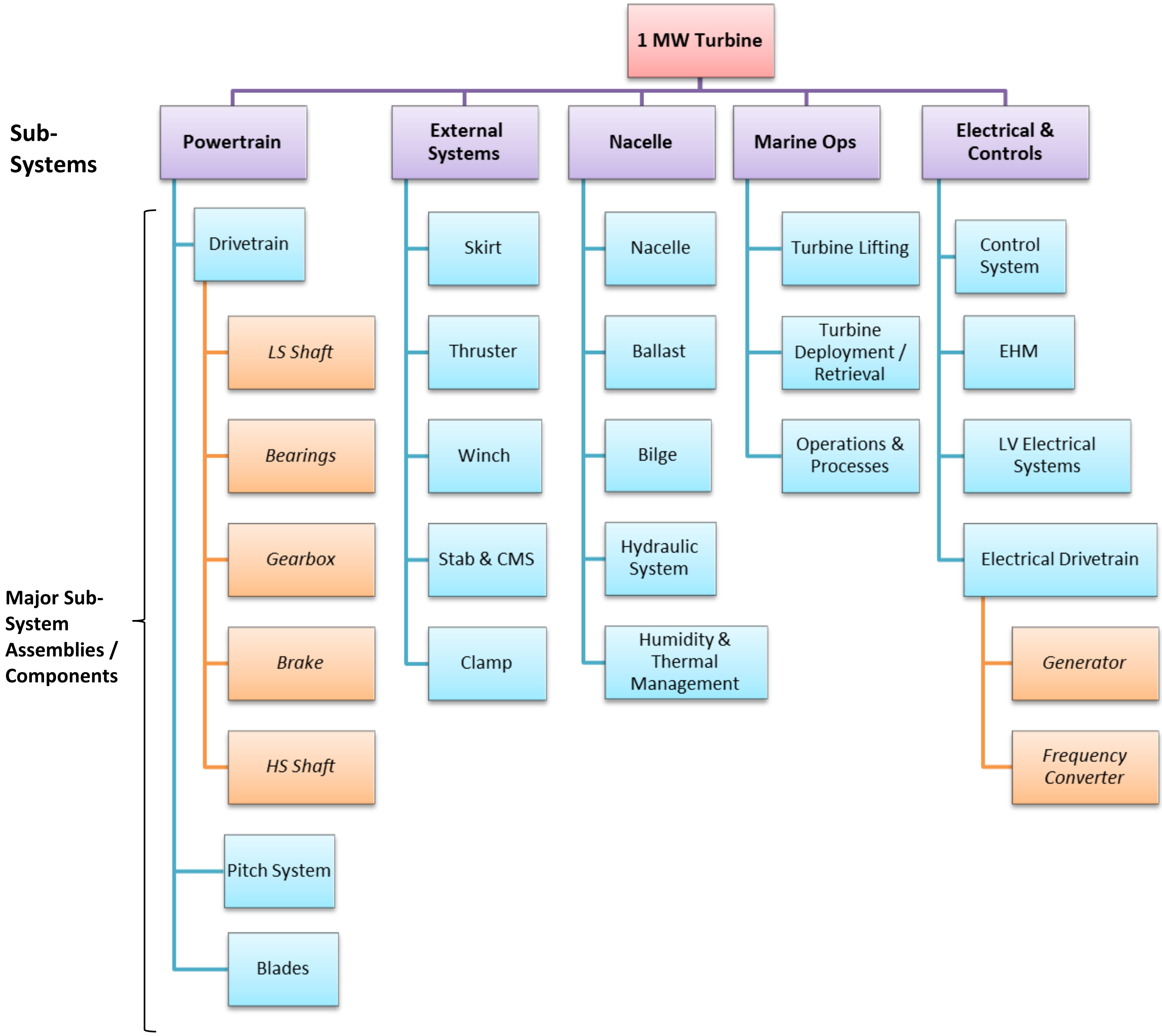

Figure 2: 1MW ReDAPT Turbine Sub-Systems (plus Major Sub-System Assemblies / Components)

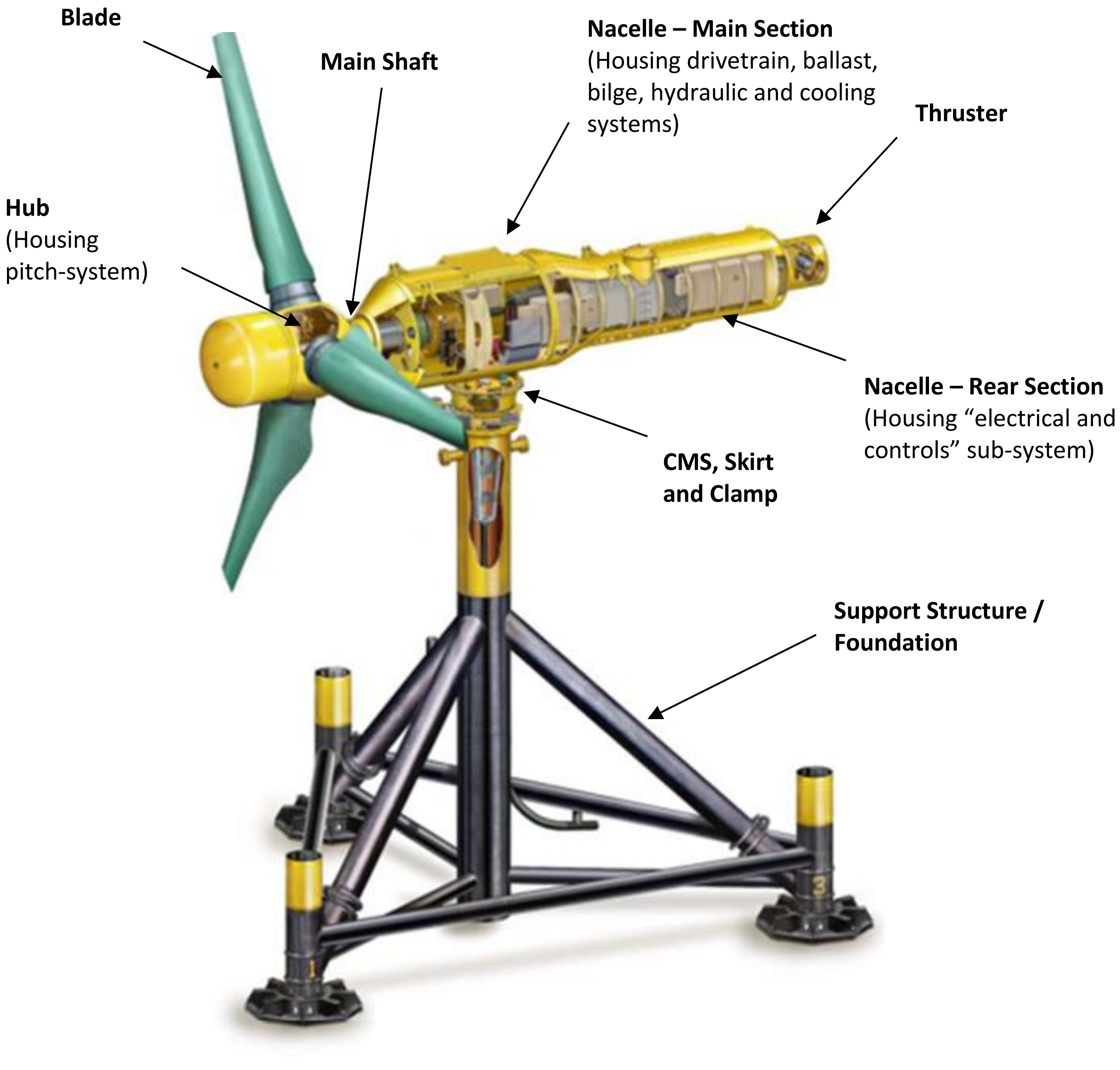

Figure 3: 1MW ReDAPT Turbine Schematic

4 SUB-SYSTEM CHECKS

Whilst sub-system checks will depend on the specific architecture of each turbine type (and the auxiliary systems included within that architecture), the following section is presented as an example of the scope of checks reasonably assumed to be required at the sub-system assembly phase of the turbine build.

The purpose of these checks would be early identification and rectification of sub-system issues prior to assembly into the turbine.

For a definition of the "sub-system" assembly phase together with a list of major sub-system components, refer to Section 3 – Assumptions.

4.1 Turbine Safety System Verifications

Purpose: The purpose of this check would be to verify that the turbine programmable safety system is wired and programmed correctly. A verified programmable safety system should be able to detect any mal-function within the turbine and should be able to shut the turbine down safely, thus protecting operators and the turbine from potential failure modes.

Hardware / Test Equipment: The turbine controls safety-system should be wired in accordance with electrical drawings.

Whilst the exact equipment requirement will be turbine dependent, the following generic equipment is recommended for the test schedule outline below:

- Laptop (with appropriate licensed controls system software installed)
- Multimeter

Checks: The checks to be completed under this heading should include (but are not limited to):

a) Visual inspection of all wires into the turbine control safety system to ensure correct cable routing
b) Inspection of all wires into programmable safety system by using a multi-meter to confirm reliable connection
c) Power-up of all ELV equipment within the safety system cabinet to confirm that the safety-system controller and all Programmable Logic Controllers (PLCs) power up
d) Check of all input-signals from PLCs and sensors to ensure at expected logic levels
e) Confirmation that input signals (via the laptop) result in expected output signals

4.2 Electrical Protection Checks

Purpose: Whilst the electrical system protective devices installed will vary depending on the philosophy of the chosen methods for protecting the turbine, typical protection relays / electrical protection devices would be used to protect against such issues as overload, over current, reverse power, earth fault, differential protection, etc. It is thus reasonable to assume that this check would encompass a high voltage (HV) switchgear "secondary injection" test to ensure that all circuit-breakers are correctly installed, set-up as intended and can be remotely reset. (Generic secondary injection testing involves disconnection of the protective device from its normal circuit and connection to a specialist test set that can inject and measure/record the required operating signal directly into the protective device relay in causing it to operate the circuit breaker).

Test Equipment: Secondary Injection Test-Set (standard equipment)

Checks: This check should use the secondary injection test-set to trigger circuit-breakers in testing safety system functionality (e.g. circuit-breaker activation, time to trigger, etc.)

4.3 Pitch System Build-Check

Purpose: The purpose of this check would be to confirm correct alignment of all turbine blade pitch system hardware during the assembly stage. (NB: this sub-system assembly check assumes that operation of the pitch-system and blade position sensors are checked at the whole turbine system level).

Test Equipment: Visual inspection only of fully assembled pitch system

Check: Visual inspection of assembled blade pitch-system to ensure all engagement settings, alignments, etc. are as required in permitting normal movement during operation.

4.4 "I/O" Box Checks

Purpose: The purpose of these checks would be to ensure that all "Input / Output" (I/O) electrical control-signal boxes located within the turbine (and any sensors / actuators with connections to / from the I/O Boxes) are functioning correctly.

Build Requirements / Test Equipment: In addition to the correct voltage supply as demanded by the boxes, the following test equipment is recommended for the test schedule outlined below:

- 4-20mA calibration device
- Resistive calibration device
- Multimeter
- Laptop for connecting to control cabinet

(***NB:*** *The above list of suggested test equipment is based upon requirements during an early production stage of the tidal turbines commercial life-cycle. For continuous production on a larger scale the functions of the above test equipment could reasonably be expected to be performed using a dedicated I/O "test-box" which plugged into each individual I/O box and performed the same functions as the equipment listed above*).

Checks / Testing: Whilst checks associated with the I/O boxes would be specific to the turbine control system architecture, the following schedule provides an example of a "generic" test-schedule with testing including (but not limited to):

a) Verification of build status of control cabinets (by inspection against drawings)

b) For each 4-20mA analogue input signal into the I/O Box:

- Disconnect sensor (if applicable)
- Connect 4-20mA calibration device into I/O Box in place of sensor
- Set 4-20mA calibration device to 4mA - check laptop returns correct value
- Set 4-20mA calibration device to 20mA - check laptop returns correct value
- Remove the 4-20mA calibration device
- Connect the 4-20mA calibration device to sensor output
- Measure current output of sensor - check that measured current is within 4-20mA.
- Disconnect the 4-20mA calibration device
- Reconnect sensor (if applicable) to the I/O Box.

c) For each 0 – 10V analogue output from the I/O Box:

- Connect multi-meter to output of the I/O Box
- Set analogue output to 0V via laptop and measure voltage using the multi-meter
- Repeat for 5V and 10V.

- Disconnect multimeter

d) For each -5 to +5V analogue input into the I/O Box:

- Connect the -5V supply to the I/O Box
- Check that the laptop is returning the correct value
- Repeat for 0V and 5V
- Disconnect the voltage supply

e) For each temperature sensor into the I/O box (e.g. *the example below assumes "PT100" sensors: $0^0C = 100\Omega / 100^0C = 138\Omega$*):

- Disconnect PT100
- Connect resistive calibration device into the I/O Box in place of the PT100
- Set the resistive calibration device to 100Ω (according to 0°C) - check laptop returning correct value
- Set the resistive calibration device to 138Ω (according to 100°C) - check laptop returning correct value
- Remove resistive calibration device
- Connect multimeter to the PT100 - measure resistance
- Check measured current is within 4-20mA.
- Disconnect multimeter
- Reconnect the PT100 to the I/O Box

f) For each digital input into the I/O Box:

- Check that I/O Box reads the correct state when the digital sensor is on / off

g) For each digital output from the I/O Box:

- Check that digital switch is on / off in line with the command

4.5 Stab and Cable Management System Build-Check

Purpose: The purpose of this check would be to perform a general check of the stab and cable management system (CMS) assemblies to ensure correct alignment during the build phase and that whilst being free to move and rotate as per design intent, there was no excessive play in the mechanism.

Test Equipment: The following test equipment is suggested for the test schedule outlined below:

- 4-20mA calibration device
- Small hydraulic power pack and appropriate hydraulic pipes/connectors

Checks: The checks to be completed under this heading should include (but are not limited to):

a) Verification of correct CMS operation (by performing visual check and rotating CMS by hand to check freely moving)

b) Use of 24V supply, milliamp meter and crocodile clips to check all alignment and positional sensors / encoders for correct functionality

c) Verification that stab plate can be raised / lowered as design intent by exercising stab several times to ensure smooth operation (may involve use of a small hydraulic power pack to drive stab)

4.6 Main Electrical Distribution Board Commissioning

Purpose: The purpose of this test would be to perform a functional test of the main electrical distribution board, and in particular consists of continuity and resistance checks across the electrical supplies for the main auxiliary systems (e.g. motors, HPUs, cooling system pumps, bilge system pumps, gearbox filter pump(s), etc).

Build Requirements / Test Equipment: This check may be split into two sections – checks prior to energising the LV supply, and checks after energising the LV supply. In performing these checks it is recommended that the main electrical LV cable be connected to a load(s), feed circuit breakers are locked, and all unconnected feed cables safely secured.

The following test equipment is recommended for the test schedule outlined below:

- Multi-meter
- Insulation resistance tester

Checks / Testing:

a) Pre-energised tests:
   - Visual inspection followed by continuity checking
   - Insulation resistance testing of each power feed where possible (e.g. 500V for 30 seconds test)

b) Post-energised tests:
   - Manual control of contactors to energise each feed circuit (plus check to confirm energisation of loads)
   - Control logic check to ensure correct control inputs / outputs are passed between main electrical distribution board and control cabinets
   - Control of each feed circuit from controller and feedback signal checks

4.7 Extra Low Voltage Distribution Commissioning

Purpose: The purpose of this test would be to complete a functional test of the extra low voltage (ELV) distribution board in ensuring that:

a) Essential and non-essential supplies are connected correctly, and
b) Power supplies share current as per design intent (within pre-determined acceptance limits)

Build Requirements / Test Equipment: With all circuits connected and insulation tests completed as necessary, the following test equipment is recommended for the test requirements outlined below:

- Clampmeter (for current measurement)

Checks / Testing:

a) Against each circuit, check circuit wiring before checking current using clampmeter

4.8 Gearbox Oil System Commissioning

Purpose: The purpose of this test would be to commission the gearbox oil system (including a quality check of oil being passed around the system to ensure early detection of potential manufacturing or assembly issues).

Build Requirements: Whilst there are no special test-equipment requirements associated with this test, it is recommended that the gearbox oil sump be connected to the oil-water heat exchanger (if a similar configuration is required in operation).

Checks / Testing:

a) Connect the oil pipes from the gearbox oil sump to the oil-water heat exchanger
b) Turn the oil pump unit (and any integral gearbox oil sampling units) on / off several times, running for approx. 5mins
c) Top up the oil level in the sump (if required)
d) Check instrumentation using the controller

*(**NB:** Gearbox instrumentation will include a number of pipe-manifold, oil tank and gearbox pressure and temperature sensors, oil quality sensors and low and high-speed shaft accelerometers and torque-sensors – the output from these sensors should be monitored during checking to ensure that all parameters remain within acceptable operating limits)*

4.9 Clamp System Functional Check

Purpose: The purpose of this test would be to check and commission the locking-mechanism (i.e. clamp) and associated systems by which the turbine will be held to the support structure whilst deployed. Confirmation that all clamp / locking system instrumentation and positional sensors / transducers are correctly calibrated and fully functional would also be expected to be included within this test.

*(**NB:** The following section assumes that the clamp / locking mechanism is hydraulically operated – where this is not the case, build requirements will differ).*

Build Requirements / Test-Equipment: The clamp / locking mechanism should be connected to an appropriately sized and commissioned HPU via hydraulic hoses to drive the mechanism closed / open. In addition, a "dummy tower top" (i.e. substitute support structure) may be required beneath the locking-mechanism, and against which it may clamp / release in checking correct orientation and operation.

The minimum level of instrumentation should include the following:

- HPU pressure gauge
- Locking-mechanism linear positional sensor(s)
- Locking-mechanism proximity sensor(s)

Checks / Testing:

a) Maximum flow-rate check – to confirm actuating time of the clamp / locking mechanism when powered by the HPU

   - Ensure clamp / locking–mechanism is fully open (and any safety latches are disengaged to allow full travel)
   - Set HPU pressure limit to maximum requirement for normal operation and drive clamp / locking-mechanism to fully closed position
   - Reverse flow and drive to fully open position
   1. Repeat checks to ensure consistent operation / time to respond

b) Instrumentation check – to confirm correct operation (and reading) of instrumentation

   - Check linear position sensor reading in fully open and fully closed positions

c) Proximity sensor check – to check operation of proximity sensors

   - In the fully closed position, record the proximity sensor reading(s)

4.10 Vessel Bridge Box Commissioning

Purpose: The vessel bridge box is a turbine power control unit located within the deployment vessel, and controls power from the ship's on-board generator(s) to the turbine when the vessel and turbine are electrically connected (e.g. via the umbilical) – the purpose of this test would be to commission the vessel bridge box power circuits.

Build Requirements / Test-Equipment: This check will be heavily bespoke to the particular design of vessel bridge box to be tested, with test-equipment / requirements dependent upon the specifics of the bridge box architecture and its intended operational controlling functions. Hence, whilst it is possible to suggest that multimeters, insulation resistance testers, phase rotation meters etc. may be required for commissioning checks, it is likely that additional testing equipment will be required – this may only be defined with knowledge of the architecture of the specific vessel bridge box to be commissioned.

Checks / Testing: As per "Build Requirements / Test Equipment", the checks to be performed (and the method of checking) will be heavily dependent upon the specific architecture and intended functioning of the vessel bridge box to be commissioned – hence the following bullet-points offer a simplified list of commissioning checks that could be used as the core checks within a larger vessel bridge box test schedule:

1. Wiring scheme checks
2. Insulation resistance check of main busbar (if applicable)
3. Insulation resistance check of all main power circuits
4. Correct panel energisation
5. Set-up of power meter
6. Set-up of insulation monitor
7. Check of voltage power supplies
8. Check of supply generator health indicators
9. Check of generator-to-turbine hand-over logic
10. Check of all safety-circuits and over-rides

4.11 Energised Frequency Converter Check

Purpose: The purpose of this check would be to ensure correct operation of the frequency converter (FC) prior to build into the turbine – it is expected that this test would be performed as part of a Factory Acceptance Test (FAT) prior to delivery to the assembly line, and as such would be performed by the manufacturer (with subsequent appropriate evidence provided that the test had been successful).

5 WHOLE TURBINE SYSTEM LEVEL CHECKS

Whilst "whole turbine system level" checks will be bespoke to the specific architecture of the turbine (and the auxiliary systems included within that architecture), the following section is presented as an example of the scope of testing required for production.

The purpose of these checks would be to capture any build issues, irregularities or malfunction of controls / instrumentation at a whole turbine system level prior to deployment.

For a definition of the "whole turbine system level" phase, refer to Section 3 – Assumptions.

5.1 Braking System and HS Shaft Speed Check

Purpose: The purpose of this check would be to ensure that the turbine rotor braking system has the correct air-gap between brake-pad(s) and brake disc in checking correct alignment, and that the high speed (HS) brake sensors are fully functional in commissioning the system to operate as per design intent in-service.

(NB: This check assumes a brake disc / calliper arrangement on the HS shaft as per the 1MW ReDAPT machine - ref. Section 3 Assumptions).

Build Requirements / Test-Equipment: Whilst no specialist test equipment is anticipated to perform this check, the braking system must be fully assembled / functional, with all sensors operational.

Checks / Testing:

a) Check of "Brake Released" sensor(s) – to ensure correct sensor operation when brake is applied / released

- Bleed brake callipers and check axial position of sensor is correct
- Release brake and check that brake sensor signal reflects brake released
- Reapply brake and check that brake sensor signal reflects brake re-applied

b) Check of shaft "Once per Rev" sensor(s) – to ensure correct measurement of shaft speed

- Release shaft brake and rotate shaft by hand (e.g. using friction strop, by rotating brake disc by hand, or other)
- Check that "once-per-rev" sensor is reading correctly

5.2 Communication checks with shore and vessel

Purpose: The purpose of this check would be to ensure that all turbine communication channels to either shore and / or support vessel (e.g. communication with all I/O boxes and cameras to a remote location) are functional and working as intended.

Build Requirements / Test-Equipment: Assembly of all I/O control cabinets should be complete, together with all shore and vessel communication links to be checked.

The following equipment may be required to perform this type of check:

- PC / Laptop with suitable HMI
- Vessel VSDL unit
- "Dummy" ROV test umbilical

Checks / Testing:

a) With the dummy umbilical wired correctly as to allow communication between PC and turbine:

- Plug dummy ROV cable into turbine's umbilical penetrator
- Check all communications links between PC and turbine are as expected to ensure required levels of communication
  e.g.
  PLCs
  I/O control boxes
  Cameras
  Etc.

5.3 Turbine Safety System Verifications

Purpose: The purpose of this check would be to verify that the whole-turbine controls safety system is wired and programmed correctly prior to deployment – this check builds upon the checks performed as part of Section 4.1, and would be performed at a whole-turbine level to ensure that any mal-function within the turbine is detected and the turbine safely shut down (where required) in protecting operators and the turbine from potential failure modes.

Hardware / Test Equipment: Whilst the exact equipment requirement will be turbine dependent, the following generic equipment is recommended for the test schedule outline below:

- Laptop (with appropriate controls system software installed and Licensed)
- Multimeter
- Radios for communications

Checks: Checks suggested under this heading could include (but are not limited to):

a) Check correct instrument inputs – ensuring that input signals match turbines programmable safety system levels

- Power up and manually triggering (i.e. push in) each proximity sensor / limit switch in turn whilst observing software signal responses
- Cover winch proximity sensor(s) and observe proximity sensor signal(s) in software for appropriate response
- Power up of vibration sensor(s) and check vibration sensor signal in programmable safety system software is being received
- Power-up frequency converter (FC) from outside turbine, ensuring FC side-trip and FC motor side-trip signal levels in programmable safety system software is "low"
- Power hydraulic safety system, ensuring correctly armed
- Check that deliberately tripping hydraulic safety system results in tripping of the programmable safety system
- Reset both software systems
- Check that deliberately tripping the programmable safety system also trips hydraulic safety system
- Reset both software systems, and check that these can also be reset remotely.

b) Check HMI outputs and logic

- Use HMI to reset programmable safety system
- Use the HMI to trigger following circuits whilst observe programmable safety system software response (using cameras, HMI report, etc. to verify successful response to programmable safety system signal):
  i. Toggle brake accumulator charge between "High" and "Low" using HMI, observing change in programmable safety system software state

ii. Toggle emergency pitch feather between "High" and "Low" using HMI, observing change in programmable safety system software state
iii. Toggle emergency stab retract between "Arm" and "Fire" using HMI, observing change in programmable safety system software state
iv. Reset all logic in HMI back to default logic conditions

- Check the following by holding Reset in HMI:
  i. Main transformer circuit breaker – check that holding reset in HMI opens circuit breaker
  ii. Frequency converter – check that holding reset in HMI stops the frequency converter
  iii. Pitch control system – check that holding reset in HMI sends pitch to feather
  iv. Brake accumulator charge valve – check that holding reset in HMI closes brake accumulator valve
  v. Hydraulic system – check that holding reset in HMI trips hydraulic system in software

c) Rotational test (if applicable)
- Program the speed monitor in the programmable safety system with an appropriate trip speed.
- Power the turbine motor to drive the turbine, and run the turbine up to that rotational speed, checking that the programmable safety system correctly trips at the pre-defined speed.

5.4 Electrical Protection Checks

Purpose: The purpose of this check would be to perform a high voltage (HV) switchgear "secondary injection" test to ensure that all circuit-breakers are correctly installed and set-up as intended at a whole turbine system level - this check builds upon those recommended within Section 4.2.

Test Equipment: Secondary Injection Test-Set (standard equipment)

Checks: Checks under this heading include (but are not limited to):

- Use of secondary injection test-set to trigger circuit-breakers in whole-turbine system level configuration in checking functionality (e.g. circuit-breaker activation, time to trigger, etc.)

5.5 Pitch System Functional Check

Purpose: The purpose of this check would be to perform a functional test of the pitch system and blade position sensors following installation within the turbine - this check builds upon the checks performed as part of Section 4.3.

Test-Equipment: This test will likely require a PC / laptop with suitable software and interfaces installed to allow exercising of the pitch system.

Checks / Testing:

a) Ensuring that the pitch-system is correctly aligned and free to rotate without obstruction:

- Connect PC / laptop to the appropriate control box, power up pitch system circuitry and ensure PC / laptop recognises pitch system
- Perform an initial manual mode test to ensure that motor and encoder correctly connected
- Perform series of motor commands to turn the pitch system through a prescribed angle whilst observing that prescribed angle is matched by true physical angle rotation

NB: Commanded angle should include "Max – Min" angle changes as well as pre-prescribed sine-wave inputs to ensure both correct output resulting from a pitch command and reaction time

5.6 Installed Ballast System Check

Purpose: The purpose of this check would be to confirm that the ballast system is performing as per design intent - this includes confirmation that the level indicator is operating correctly, the ballast system may be activated without leakages, and that the ballast pump is fully functional (in both directions).

Test-Equipment: It is envisaged that the following equipment would be required to perform a ballast system check:

- Water supply
- Drain
- Flow meter

Checks / Testing: Following a check of all electrical connections and torqued fasteners, the following test-schedule is suggested:

a) Preparation (prior to filling tank):

- Attach flow meter to water supply and ensure all joints around system are dry

b) Level indicator check – ensuring correct response from level indicator to filling tank

- Use turbine control system to begin filling tank, ensuring tank level indicator responds
- Compare flow meter reading with turbine's level indicator to confirm accuracy of system
- Check all connections remain dry post-test

c) Directional check – ensuring that pump is functional in both directions

- Using turbine control system, operate pump to move representative volume of ballast-water from aft tank to the forward tank (or vice-versa dependent upon initial test set-up)
- Reverse pump / flow such that water moving in opposite direction - confirm direction of movement by monitoring tank level indicators
- Check all connections remain dry post-test

NB: In the event that the turbine is to be subsequently transported post-test, it is recommended that the ballast system be drained down prior to transportation – this will require the system to be re-charged on arrival at site

5.7 Installed Bilge System Test

Purpose: The purpose of this check would be to test functionality of the bilge system - this includes testing of the float switch (fail safe) and analogue sensor(s).

Test-Equipment: It is recommended that in performing this check, a drainage container of greater than 10 litres is used to capture water that is pumped out of the turbine.

Checks / Testing:

a) Check setup

- A drainage container should be placed under the bilge pump outlet to catch any water displaced from the turbine during this check

b) Analogue sensor check - to confirm sensor responds as expected to bilge filling with water

- Manually fill bilge with water until bilge pump activates, continuing to fill for a further 3 minutes
- Monitor analogue sensor value as pump removes water from bilge

- Check that control system stops bilge pump when remainder at correct level for analogue sensor

c) Float Switch – to confirm float switch triggers pump when water level reaches high trigger point

- Turn analogue sensor off and fill bilge with water (such that float switch rises to high position)
- Monitor that bilge pump triggers as high position reached and de-activates when low position achieved

NB: It is recommended that any residual water in the bilge system is removed prior to transportation

5.8 Earth Fault Detection

Purpose: The purpose of this check is to ensure that the LV (i.e. < 1000v) earth fault detection systems on the low voltage electrical networks are functioning correctly. This includes testing the detection systems by inserting resistances into the network and detecting the level of earth resistance.

Build Requirements / Test-Equipment: Test equipment is necessary to switch a small resistor of known value into the circuit between phase and earth.

Checks / Testing:

a) Install the test unit into the LV system.

b) Energise the LV network and ensure that the earth fault value is a very high value consistent with the LV network design. Ensure value is correctly read into the turbine control system.

c) Switch resistor onto the network. Ensure that earth fault value in turbine control system changes according to the resistor value

d) Switch out the resistor and check that value returns to the initial value

5.9 Umbilical Cable Connection Check

Purpose: The purpose of this test is to ensure that power and communications are operating correctly through the umbilical cable connection.

Build Requirements / Test-Equipment: The turbine HMI is required as well deployment vessel umbilical interface unit or quayside umbilical interface unit. The umbilical interface unit allows power to be connected to the umbilical power cores and Ethernet connection to be made to the umbilical communication cores.

Checks / Testing:

a) Connect the umbilical to the turbine and the umbilical interface unit

b) Connect power to the turbine

c) Ensure that communication is possible to the turbine through the HMI. A bandwidth checking utility can be used to check that the correct data communication rate is being achieved

d) Ensure that auxiliary systems can be powered such as cooling pumps. Check auxiliary system voltage on all phases and check direct of phase rotation is correct.

5.10 Hydraulic System Functional Check

Purpose: The purpose of this check would be to ensure correct operation of the hydraulic system at a whole turbine system level, and would require to be performed once the hydraulic circuit was complete (e.g. with the engagement module connected to the Turbine).

Build Requirements / Test-Equipment:

It is recommended that for this check the full hydraulic system (e.g. engagement module, clamp, etc.) be fitted, with all main and auxiliary power systems (e.g. battery back-up system) operational. Before commencement of these checks, all instrumentation relating to the hydraulic system together with all safety sensors and protection logic / circuitry should have been tested and approved.

NB: Throughout this check, careful attention should be paid to the HPU and all hoses / connections to ensure there are no leaks of hydraulic fluid anywhere in the system.

The following equipment is suggested for this check:

- Dummy Tower Top (for engagement by clamp / locking mechanism)

In addition, where the braking system is hydraulically operated, it is suggested that this system is fully checked and commissioned prior to performing the brake system hydraulic check below.

Checks / Testing:

a) Brake check – to ensure hydraulic system can apply / release brake

- Ensure all hydraulic lines brake system are correctly connected within the turbine and that Hub, Low Speed and High Speed Shaft clear of obstructions
- Ensure suitable monitoring for potential shaft rotation (e.g. visual observation)
- Activate the HPU, and select appropriate pressure to operate brake
- Activate brake and cycle “open / closed”, verifying correct operation by checking brake proximity sensor signal(s) from turbine controller

b) Stab / CMS rotational drive - to check hydraulic system is able to rotate stab / CMS as required

- Ensure all Hydraulic lines to stab system are correctly connected within the turbine and that stab plate fully retracted
- Ensure suitable monitoring for CMS rotation (e.g. visual observation)
- Activate HPU, and select appropriate supply pressure
- Rotate stab plate fully in one direction
- Rotate stab plate fully in opposite direction
- Ensure turbine controller receives signals from Stab/CMS system to indicate rotational position

c) Stab ram actuator - to ensure hydraulic system operates stab-rams as required

- Ensure that stab plate is fully retracted and correctly aligned in rotation over mating plate
- Ensure suitable monitoring of stab position (e.g. visual observation)
- Turn on the HPU, and set supply pressure appropriately
- Advance ram

- Retract ram
- Ensure all hoses are arranged correctly such that advancing / retracting ram does not cause chafing
- Ensure turbine controller receives correct signals from stab system to indicate stab position

d) Yaw clamp / locking mechanism operation - to check hydraulic system activates clamp

- Engage dummy tower top below clamp / locking mechanism
- Ensure suitable monitoring of clamp movement / operation (e.g. visual observer)
- Turn on HPU and set to appropriate supply pressure
- Drive clamp / locking mechanism to closed position
- Drive clamp / locking mechanism to open position

5.11 Cooling System Flow Balance Check

Purpose: The purpose of this check would be to ensure that the cooling system flow balance (e.g. between generator, gearbox cooler, transformer, frequency convertor and any other system within the cooling-system circuitry) is correctly set-up.

Build Requirements: It is recommended that the cooling system should be filled, bled and pressurised in accordance with standard build procedures to perform this check, with all cooling system flow meters and pressure sensors commissioned / operational.

Checks / Testing:

a) With all fill, drain and bleed point valves closed and system pressurised, check system for leaks
b) Confirm circuit accumulator valves are open (i.e. transformer circuit, frequency converter circuit, gearbox circuit, etc.).
c) Confirm all maintenance shut off valves and heat-exchanger valves are open
d) Fully open flow control valves to generator loop, transformer loop and secondary circuit(s)
e) Record pre-charge pressure readings around system at each station
f) Turn on primary circuit cooling pump - ensure no leaks in the primary cooling system
g) Record flow sensors and pressure sensors
h) With the primary circuit cooling pump still running adjust flow control valves to generator and transformer to achieve expected operational flow rates - record flow rates and pressures around system
i) Turn off primary circuit pump and wait 5 minutes
j) Re-activate pump and record pressures / flow rates again
k) Turn off primary circuit pump
l) Turn on secondary circuit pump - check for leaks - record flow rates and pressures
m) Adjust flow control valve to gearbox to achieve expected operational flow rate
n) Record the flow and pressure readings:
o) Turn off secondary circuit pump and wait 5 minutes
p) Re-activate secondary pump and record pressures / flow rates again
q) Confirm all pressures and flow rates are as expected

5.12 I/O Box Checks

Purpose: The purpose of these checks at a whole turbine system level would be to confirm correct integration and operation of the individual I/O boxes (each of which was checked at the "sub-assembly" stage of the build-line process, as referred to in Section 4.4) as a complete integrated system. Hence, these checks would ensure that all "Input / Output" (I/O) electrical control-signal boxes located within the turbine (and any sensors/actuators with connections to / from the I/O Boxes) remained functioning correctly at the whole turbine level.

Build Requirements / Test Equipment: In line with Section 4.4, and in addition to the correct voltage supply (as demanded by the boxes), the following test equipment is recommended for the test schedule outlined below:

- 4-20mA calibration device
- Resistive calibration device
- Multi-meter
- Laptop for connecting to control cabinet

(NB: The above list of suggested test equipment is based upon requirements during an early production stage of the tidal turbines commercial life-cycle. For continuous production on a larger scale this test could reasonably be expected to be performed using a dedicated "I/O Test Rig" test-box which plugged into the main control systems I/O box and performed a similar task to the equipment list detailed above).

Checks / Testing: The checks / testing associated with I/O boxes will be bespoke to the control system architecture however the following provides an example of a "generic" test-schedule. Hence, testing recommended under this heading should include (but is not limited to):

a) Verification of build status of control cabinets by inspection against drawings

b) For each 4-20mA analogue input signal into the I/O Box:

- Disconnect sensor and connect 4-20mA calibration device in place of sensor within I/O box
- Set 4-20mA calibration device to 4mA and check that laptop returns correct value
- Set 4-20mA calibration device to 20mA and check that laptop returns correct value
- Remove 4-20mA calibration device
- Connect 4-20mA calibration device to output of sensor
- Measure current output of each sensor, checking that measured current is within 4-20mA.
- Disconnect 4-20mA calibration device and reconnect sensor to I/O Box.

c) For each 0 – 10V analogue output from the I/O Box:

- Connect multimeter to output of the I/O Box
- Set analogue output to 0V using laptop command - measure voltage using multimeter
- Repeat for +5V and +10V.
- Disconnect multimeter

d) For each -5 to +5V analogue input into the I/O Box:

- Connect -5V supply to I/O Box - check that laptop is returning correct value
- Repeat for 0V and +5V
- Disconnect the voltage supply

e) For each temperature sensor into the I/O box (*the example below assumes "PT100" sensors: $0^0C = 100\Omega$ / $100^0C = 100\Omega$*):

- Disconnect PT100 sensor
- Connect resistive calibration device into I/O Box in place of the PT100.
- Set resistive calibration device to 100Ω (according to 0°C) and check that laptop returns correct value.
- Set the resistive calibration device to 138Ω (according to 100°C) and check that laptop returns correct value

- Remove resistive calibration device.
- Connect multimeter to PT100 sensor and measure resistance
- Check that measured current is within 4-20mA
- Disconnect the multimeter
- Reconnect PT100 sensor to I/O Box

f) For each digital input into the I/O Box:

- Check that I/O Box reads correct state when digital sensor is on / off

g) For each digital output from the I/O Box:

- Check that digital switch is on / off in line with the command

5.13 EHM Full System Acceptance Check

Purpose: The purpose of this check would be to ensure that the equipment health monitoring system (EHM) is fully functional and operating as required (e.g. the full EHM data suite can be acquired, transmitted to a shore-side location and logged / accessed).

Build Requirements / Test-Equipment: This test would require loaded running of the turbine, with the following test equipment typical of that required for an EHM full system acceptance check:

- 24V DC power supply to the turbine
- Turbine controller reset signal
- "Shore side" PC
- Laptop to run HMI, with Ethernet to turbine
- Large (e.g. 14Tb) data-storage drive

Checks / Testing: Pre-test visual inspection of sensor wiring and excitation of sensors / measured HMI signal to be completed prior to test – all sensors that are read by EHM system should be powered up by shore-side PC for test

a) With the turbine performing loaded running, check that laptop HMI able to control "shore side" computer in checking logging of full EHM sensor suite can be started and stopped
b) Via turbine controller, apply reset signal to EHM system ensuring EHM system turns off in a safe manner and re-sets
c) During running, remove Ethernet link from shore side PC to check turbine EHM system starts logging data
d) With link re-established, check data streamed to shore side PC
e) Check that data logged from each EHM sensor fitted to turbine

5.14 Stab and CMS Continuity Check

Purpose: The purpose of this check would be to ensure that the stab and CMS fibre optic cables (which are susceptible to damage during the build process) retain continuity and remain functional post-build (i.e. in-situ).

Test-Equipment: This test requires the following equipment (or similar):

- Fibre optic transmitter
- Fibre optic receiver

Checks / Testing:

a) Check that fibre optic cables are correctly routed and connected as required

b) Measure losses through stab / CMS assembly

- Attach fibre optic transmitter to input end of a stab / CMS connector within turbine
- Attach fibre optic receiver to output end of respective stab / CMS cable
- Check wave-length losses of receiver vs. transmitted signal
- Repeat for all stab / CMS fibre optic cables

5.15 End to End Checks for Strain Gauges

Purpose: The purpose of this check would be to ensure that all major instrumentation is correctly installed and validated, and is capable of transmitting the necessary data in accordance with requirements.

Such instrumentation would include:

- Blade, shaft, gearbox and nacelle strain gauges (to measure forces present on the equipment when turbine is installed)

Build Requirements / Test-Equipment: All strain gauge wiring should be complete from interrogator unit to final blade / shaft connection point - ensure ethernet and power-wiring to interrogator units are correct, with appropriate low voltage power and interconnection to a shore computer.

The following equipment is typical of that required to perform end-to-end strain gauge checks:

- Computer connected to turbine Ethernet network, loaded with appropriate test software to capture / communicate / display data from interrogator units
- Test strain gauge(s)

Checks / Testing:

a) Full check of connected strain gauges and data-logging system

- Ensure power and Ethernet connections to relevant interrogator units
- Run software application on networked PC and ensure connection made to hardware
- Run application in basic acquisition mode and check all strain-gauge channels are displayed as being present
- Use software to input data into system and record data feedback from channels
- Check data-logs to ensure all channels passing data freely

b) Individual check of strain gauge channels

- Run software application in basic acquisition mode
- Identify physical strain gauge connection points on turbine and trace connection to furthest point scanning unit and connect test strain gauge into this connection point
- Check test strain gauge is registering on display screen
- Flex test strain gauge - check for resultant shift in wavelength on screen
- Repeat for all other strain gauge channels

5.16 Central Distribution Board Commissioning

Purpose: The purpose of this test would be to complete the functional test of the central distribution board (CDB) previously performed at a sub-assembly level (see Section 4.6) by performing this test at whole-turbine level, with all hardware circuits complete.

Build Requirements / Test-Equipment: These checks should include testing both:

- prior to energisation with the LV supply, and
- post energisation of the LV supply

The following equipment is typical for this type of check:

- Multimeter
- Insulation resistance tester

Checks:

a) Pre-energisation checks:
   - Visual inspection of CDB and continuity checks across all CDB connections (e.g. pitch system, ballast pump, bilge system, etc)
   - Insulation resistance check of each power feed (where possible)

b) Post-energisation checks:
   - Check manual control of contactors to energise each feed circuit. Rudimentary checks to confirm energisation of loads
   - Check control logic to ensure correct signals passed between CDB and other control cabinets
   - Check of feed circuit control from controller (and feedback signals)

5.17 Extra Low Voltage Distribution Commissioning

Purpose: The purpose of this test would be to complete a functional test of the extra low voltage (ELV) distribution board at a whole-turbine level (i.e. with all turbine systems installed and circuitry complete) in ensuring that:

a) Essential and non-essential supplies are connected correctly, and
b) Power supplies share current as per design intent (within pre-determined acceptance limits)

This check would build upon the checks performed at a sub-system assembly level as referred to in Section 4.7.

Build Requirements / Test Equipment: With all final-turbine hardware and circuits connected and final insulation tests completed as necessary, the following test equipment is recommended for the test requirements outlined below:

- Clampmeter (for current measurement)

Checks / Testing:

a) Against each circuit, check circuit wiring is correct
b) Against each circuit, check current is correct

5.18 Gearbox Oil System Check

Purpose: The gearbox oil system is commissioned at the sub-assembly stage as per Section 4.8 – the purpose of this check would be to ensure that the gearbox oil system remained fully functional at a system level when fully integrated into the turbine.

Checks / Testing:

a) Ensure all oil pipes are connected from gearbox oil sump to oil-water heat exchanger with no leaks
b) Activate / deactivate oil pump unit (and any integral gearbox oil sampling units) via the central control board several times, running for approx. 5mins each time

c) Check level of oil in sump at end of test to ensure no oil loss
d) Check instrumentation using the controller (*see note below*)

(NB: Gearbox instrumentation will include a number of pipe-manifold, oil tank and gearbox pressure and temperature sensors, oil quality sensors and low and high-speed shaft accelerometers and torque-sensors – these should all be monitored during testing to ensure all parameters remain within acceptable operating limits).

5.19 Anti-Condensation Heaters

Purpose: The purpose of this test would be to complete a functional test of the anti-condensation heaters (ACH) to ensure that all ACH units were correctly integrated and functioning as per design intent.

Build Requirements / Test-Equipment: This test should be performed at a whole turbine system level, with the following equipment recommended:

- Current clampmeter
- Non-contact thermometer

Checks / Testing:

a) For each of the distribution boards:
    - Check status of circuit breakers and visually inspect ACH load connections to ensure ACHs isolated
    - Activate ACHs and measure current with clampmeter (measuring total ACH load drawn from ACHs connected to distribution board)
    - Measure current from ACH units (from cold) at
        - Switch on
        - After 1 minute
        - After 5 minutes
        - After 30 minutes
    - Measure temperature rise of ACH units 30 minutes after switch on
    - De-activate ACHs.

5.20 Thruster Oil System Pressure Check

Purpose: It is likely that where a thruster is incorporated for yawing of the turbine, this would necessitate use of hydraulic hoses external to the nacelle. The purpose of this check would be to perform a thruster system oil pressure check in ensuring that all thruster hose clamps and penetrators were leak-free, thus safeguarding against oil-leaks into the sea during deployment.

Build Requirements / Test-Equipment: It is recommended that this check be performed on the fully assembled thruster oil system as part of the whole turbine system level checks. The following equipment is suggested:

- Hydraulic pump
- Oil hose (plus end fixings) of working pressure > maximum penetrator working pressure
- Pressure gauge

Checks / Testing:

a) Penetrator leak-check:
    - Connect oil hose between "wet" side of penetrator and hydraulic pump, ensuring all connections are tightened and leak-free

- Activate hydraulic pump, slowly building pressure within hose to maximum penetrator working pressure
- Hold for a pre-determined length of time, ensuring pressure reading remains constant
- Release pressure and ensure no oil leaks have occurred

b) Low pressure test:

- Connect pressure gauge to a thruster oil system port
- Using gauge reading, compress thruster oil system pressure-compensator to maximum pressure
- Hold for a pre-determined length of time, ensuring gauge remains constant with no oil system leaks
- Release pressure and remove gauge

5.21 Clamp System Functional Check

Purpose: This check builds upon that performed at a sub-system level (see Section 4.9), and would be performed to ensure correct clamp / locking system operation at a whole turbine system level. Confirmation that all clamp / locking system instrumentation and positional sensors / transducers are correctly working at the whole turbine system level would also be included within this test.

Build Requirements / Test-Equipment: The clamp / locking mechanism should be connected to the turbine hydraulic and control systems which should be commissioned and fully operational. In addition, a “dummy tower top” (i.e. substitute support structure) may be required beneath the locking-mechanism, and against which it may clamp / release in checking correct orientation and operation.

The following turbine instrumentation / circuitry should also be fully commissioned:

- Hydraulic system pressure gauge
- Locking-mechanism linear positional sensor(s)
- Locking-mechanism proximity sensor(s)

During this check the hydraulic system should be monitored for leaks.

Checks / Testing:

a) Maximum flow-rate check – to confirm actuating time of the clamp / locking mechanism when powered by the turbine system HPU / hydraulic circuit
   - Ensuring clamp / locking–mechanism is fully open activate turbine HPU in driving clamp / locking-mechanism to fully closed position (ensuring time taken is within operating limits)
   - Activate HPU in driving to the fully open position (ensuring time taken is within operating limits)
   - Repeat test, ensuring times are consistent

b) Instrumentation check – to confirm correct operation (and reading) of instrumentation
   - In fully open position, record linear position sensor reading before driving locking mechanism closed
   - In fully closed position, record linear sensor reading
   - In the fully closed position, record the proximity sensor reading(s)

5.22 Battery System

Purpose: The purpose of this check is to ensure the turbine battery systems are functioning correctly and that the batteries are charged and capable of being charged.

Build Requirements / Test-Equipment: UPS PC interface software and connection lead for interrogating the battery system UPS. Battery test meter capable of measuring internal resistance as well as battery voltage

Checks / Testing:

a) Test all batteries and record voltage and internal resistance values. These values should be in accordance with Manufacturer's specification. Checks should be made once batteries are fully charged.

b) Power up the turbine UPS system, connect the UPS connection lead and start interrogation software

c) Check UPS health indicators while charging batteries and ensure values are in accordance with expectation

d) Disconnect LV power and continue to monitor UPS through interrogation software.

e) Check UPS continues to provide power to the control system

f) Reconnect LV power and check that UPS resumes charging the battery pack

5.23 Frequency Converter Synchronisation

Purpose: The purpose of this check would be to build upon the FAT test (covered in Section 4.11) and would be performed at a whole turbine system level in synchronising the frequency converter to the power supply, and to magnetise the induction generator.

Build Requirements / Test-Equipment: No specialist equipment is required for this test.

Checks / Testing: This check will be bespoke to the individual frequency converter being tested however any check would be expected to include:

- Magnetisation of the generator, and
- Synchronisation to the grid / power supply

5.24 System wide time stamp check

Purpose: The purpose of this test would be to ensure that all data timestamps across all systems were consistent. This is necessary as it ensures that all data collected (EHM, wave condition, flows, etc.) could be matched to specific time periods in permitting subsequent cross-referencing and interrogation of data.

Build Requirements / Test-Equipment: No specialist equipment is required for this test.

Checks / Testing: This check will be bespoke to the individual software system being demonstrated however the following steps provide generic examples of the type of testing encompassed:

a) Verification of remote connection / control of turbine (i.e. off-site)
    - Verify that turbine may be logged in and controlled remotely

b) Verification of remote connection to turbine GPS unit
    - From each PC "Ping" the GPS clock using the specific IP address

c) Verification Time sync #1
    - Verify that PC time is correct with all other PCs

d) Verification Time sync #2
    - Using GPS Config application alter time within GPS unit
    - Verify that the PC time is correct with all other PCs

e) Verification Time sync of other equipment

- Using GPS Config application alter time within GPS unit
- Verify that all other equipment time is correct with other PCs

f) Verification for daylight saving

- Using GPS Config application alter time within GPS unit to reflect daylight saving change
- Verify that all other equipment time is correct with other PCs

5.25 Winch Radio Frequency Communication and Camera Check

Purpose: This check assumes communication from the support vessel to the turbine via a radio frequency (RF) system on the deployment / retrieval winch, and that the turbines deployed monitoring system incorporates internal / external subsea cameras. The purpose of this check would be to ensure functionality of that control and video transmission system from the turbine to the vessel.

Build Requirements / Test-Equipment: This check would require a "shore-side" laptop connected to the turbine and a dummy winch with full radio frequency (RF) communication capabilities in order to check functionality of the corresponding system as part of a whole turbine system level check. It may also require a dummy control rack to mimic function of the support vessel control rack.

Checks / Testing:

a) Set laptop up with turbine HMI software and connect turbine HMI laptop to turbine bridge box
b) Connect ethernet between bridge box and dummy ship control rack
c) Power up the required communications circuitry
d) Ensure dummy-winch positioned on turbine (via connected umbilical)

e) Test the command transmission:

- Using turbine HMI on "vessel", activate functions to operate systems within turbine (e.g. turn lighting on and off) to check turbine functional control by "vessel" HMI via RF communications system

f) Test the video transmission:

- Select a camera within turbine - position a person in front of camera (with 2-way radio) whilst another person operates turbine HMI screen. Use hand signals and radio communication simultaneously to check for clarity of signal / delay in video transmission

g) Combine the two checks above simultaneously to ensure no degradation of either command signal transmission or video transmission

h) Repeat for remaining cameras to ensure multi-camera functionality

5.26 De-humidifier Check

Purpose: The purpose of this check would be to ensure that the turbine's internal dehumidifier was fully operational. It would also measure the rate at which the dehumidifier removed moisture from air inside the nacelle in ensuring acceptability at a whole-turbine system level.

Build Requirements / Test-Equipment: It is recommended that a humidity calibration kit be used for this test with capability to locally emit a calibrated level of moisture into the surround atmosphere (with the equipment set to a relative humidity level of 50% or greater). It is also recommended that this test be performed within a sealed turbine.

Checks / Testing:

a) Ensuring dehumidifier is powered up, place humidity calibration kit close to dehumidifier and activate - confirm dehumidifier is operational

b) De-activate power to dehumidifier and seal turbine

c) Monitor temperature and relative humidity sensor readings within turbine in allowing build-up of humidity to pre-determined levels (i.e. above upper operational limit)

d) Return power to dehumidifier and check time to return temperature and relative humidity levels to below lower operation values

5.27 Major Flange Sealing-Integrity Check

Purpose: The purpose of this check would be to ensure that all major nacelle flange seals were fitted and seated correctly.

Build Requirements / Test-Equipment: Whilst this check will be bespoke to the design of flange being tested dependent upon geometry and size, it is likely that either a source of compressed air and / or a vacuum pump (together with appropriate pressure gauges) will be required.

Checks / Testing:

As stated above, this test will be heavily dependent upon geometry and size of the flange to be tested and hence it is not possible to present a generic test-schedule in this instance, however any pressure / vacuum test across a flange should include the following steps:

- Pre-pressurisation visual checks to ensure seals are correctly seated
- Pressurisation over a suitable volume such that leak-detection (via pressure gauges) would be possible
- Pressurisation for a length of time to ensure slow-leak detection
- Correct application of either positive or negative pressure to ensure changes in pressure during the checking process do not displace the seals being tested

5.28 Turbine Hibernation Check

Purpose: The purpose of this check would be to ensure that the turbine could be placed into a dormant state and re-activated at a whole-system level remotely.

Build Requirements / Test-Equipment: Whilst this check would be bespoke to the turbine control system architecture it is likely that such a check would require some external means of communication with the turbine (e.g. winch proximity sensors) in transferring communications to the turbine control system. In addition, any back-up power supply (e.g. an auxiliary battery power pack) would be required to be charged / fully operational.

Checks / Testing:

a) Prepare turbine software for hibernation, ensuring any back-up battery power supply is fully charged

b) Disconnect main turbine power supply, leaving control system to run for extended period in idle state on back-up power supply

c) Hibernate control system using laptop / HMI into main control system - leave turbine in hibernated state for a fixed period

d) Awaken turbine control system using external communications sensor (e.g. winch proximity sensor)

e) Repeat check for each sensor / external communications source intended to have capability to awaken turbine from dormant state

5.29 Vessel Bridge Box Commissioning

Purpose: This check would build upon the checks recommended in Section 4.10 (at the individual vessel bridge box sub-assembly stage), and aims to check that full control of turbine functionality is achievable via the vessel bridge box.

Build Requirements / Test-Equipment: This test will be heavily bespoke to the particular design of vessel bridge box and turbine control system architecture, with test-equipment / requirements dependent upon the specifics of both units. Hence, whilst it is possible to suggest that multimeters, insulation resistance testers, phase rotation meters etc. may be required for commissioning checks, it is likely that additional testing equipment will be required – this may only be defined with knowledge of the specific architectures involved.

Checks / Testing: As per "Build Requirements / Test Equipment", the checks to be performed (and the method of checking) will be heavily dependent upon system architecture, however turbine whole-system commissioning checks may include the following:

a) Connection of vessel bridge box (or dummy test unit) to turbine
b) Energisation of bridge box
c) Energisation of turbine control circuitry via bridge box
d) Check of voltage power supplies
e) Check of turbine health indicators
f) Check of turbine basic functions via bridge box
g) Check of turbine safety functionality via bridge box

5.30 Emergency Clamp Close Check

Purpose: The purpose of this check would be to ensure that in the event of grid loss whilst the clamp / locking mechanism is partially open (i.e. during a yaw procedure), the locking mechanism will prevent loss of the turbine from the support structure (i.e. it will immediately close, with power to the HPU being supplied by the on-board back-up power supply).

Build Requirements / Test-Equipment: Whilst no specialist equipment is envisaged for this check, it should be possible to simulate a grid loss event (e.g. by opening the circuit breaker for the main HV turbine power-feed). In addition, a dummy tower-top may be required (upon which the clamp / locking mechanism can engage).

Checks / Testing:

a) Circuit Check
   - Ensuring turbine is energised with clamp / locking mechanism fully closed, open main HV power feed circuit breaker
   - Confirm that control system switches turbine into "grid loss failure" mode (or similar)
   - Re-close circuit breaker and confirm turbine has reverted back to standby mode

b) Emergency clamp close
   - Ensuring turbine is energised with clamp / locking mechanism fully closed, ensure on-board back up power supply is fully charged (with circuits activated)
   - Energise HPU and open clamp to bearing (i.e. yawing) position
   - Open main HV power feed circuit breaker
   - Confirm that control system switches turbine into a grid loss failure mode
   - Ensure that locking mechanism has reacted appropriately in performing an emergency close (thus locking onto dummy tower top)
   - Re-close circuit breaker and confirm turbine has switched back to standby mode

6 DEPLOYED COMMISSIONING CHECKS

Whilst deployed commissioning checks will be bespoke to the specific architecture of each turbine type (and the auxiliary systems included within that architecture) as well as the method of deployment, the following section is presented as an example of the scope of core-checks reasonably assumed to be required whilst commissioning a deployed turbine.

The main purpose of these checks is to ensure that in commissioning the turbine, the health monitoring systems (and associated hardware) are fully operational prior to customer hand-over.

For a definition of the "deployed commissioning" phase, refer to Section 3 – Assumptions.

6.1 Braking System Bedding In Check

Purpose: The purpose of this check would be to ensure that the HS shaft brake disc / calliper arrangement had been bedded in correctly. This check may only be performed during deployment due to the high levels of torque required to drive the shaft as the brake is being applied.

(NB: This check assumes a brake disc / calliper arrangement on the HS shaft as per the 1MW ReDAPT machine - ref. Section 3 Assumptions).

Check: Upon first deployment the brake system (i.e. with a new disc and pads) will require to be bedded-in to ensure subsequent braking performance of the rotor as per design intent. Whilst this process will be bespoke to the braking system it would likely include the following:

a) With turbine deployed and activated, release shaft brake and allow the rotor to work up to a steady rate of rotation
b) Apply brake - observe number of rotations until shaft has stopped
c) Release brake and repeat process - observe number of rotations until shaft has stopped
d) Compare number of shaft rotations for (b) and (c)
e) Repeat process until number of rotations has become constant at which point brake can be considered bedded-in.

(**NB:** During each bedding-in cycle the flow-rate will be required in order to calculate rotor torque – this is required to ensure that the torque level may be accounted for in comparing the number of rotations during each bedding-in cycle)

6.2 Shore / Vessel Communications Check

Purpose: This check builds upon checks recommended in Section 5.2 (performed at a pre-deployed whole turbine system level) – the purpose of this check would be to ensure that all communication channels between turbine and shore / vessel (e.g. communication with all I/O boxes and cameras) have been correctly commissioned and remain functional in the deployed state.

Check: This check will be bespoke to each turbine's control and communications system architecture, but should include the following commissioning checks –

a) Check of all communications links between vessel and turbine (via umbilical) as required to ensure expected levels of communication – E.g.
   - PLCs
   - I/O control boxes
   - Cameras
   - Etc.
b) Check of all remote communications links between shore and turbine as required to ensure expected levels of communication – E.g.

- PLCs
- I/O control boxes
- Cameras
- Etc.

6.3 Emergency Stops Check

Purpose: The purpose of this check would be to ensure that the turbine can be brought under control and placed into a safe state from a remote location in the event that it becomes necessary to perform an emergency shut-down of the turbine during operation.

Check: This check will be bespoke to each turbine's controls safety system architecture, but should include the following commissioning checks –

a) Ensuring wet mate connections mated in manual mode and all communications operating - test safety system by pressing shore based HMI emergency stop (triggering turbine transfer into safe mode)
b) Ensure correct alarms activated before returning turbine to manual mode
c) Repeat procedure for all alternative means of performing shore-based emergency stop

6.4 Electrical Protection Check

Purpose: The purpose of this check is to ensure that all electrical protection settings on programmable protection relays are correctly set and are functioning correctly.

Check: This check will be bespoke to each turbine's electrical protection system architecture, but should include the following commissioning checks –

a) Using a "secondary inject test set" the protection settings of all programmable, or manually settable, protection relays should be tested and checked against the design specification

6.5 Pitch System Functional Check

Purpose: The purpose of this check would be to ensure that the blade pitch-system remained fully functional in the deployed condition, to prove pitch system response time and to ensure that the pitch system returned to the feathered state (if commanded) in the event of a turbine shut-down.

Check: This check will be bespoke to each turbine's specific blade pitch-system architecture (if applicable), but it is recommended that testing be performed during slack water with the following commissioning checks included:

a) Manual pitch of rotor blades from minimum blade pitch angle up to maximum blade pitch angle and back down to minimum
b) Full check of all blade pitch sensors (e.g. oil temperature, oil pressure, pitch speed, pitch angle, gear temperatures, etc.) to ensure both functionality of instrumentation and that all parameters remain within acceptable working levels
c) Check of an appropriate response in event of emergency command to feather blade pitch

6.6 Installed Ballast System Check

Purpose: The purpose of this check would be to ensure that the ballast system remained fully functional in trimming the turbine during first deployment.

Check: It is likely that upon first deployment a degree of ballast transfer will be required to correctly trim the turbine. Whilst this process will be bespoke to the system architecture, the following checks should be included:

a) That the ballast system remains fully functional in the deployed state
b) That the ballast system contains sufficient ballast to correctly trim the turbine
c) Post-check, that the turbine remains in the correctly trimmed state with the ballast system dormant

6.7 EHM and SCADA Full System Acceptance Check

Purpose: The purpose of this check would be to ensure that the turbine EHM and SCADA systems were fully functional in the deployed condition, and that the link / relay of data back to the remote shore station was working as expected.

Check: This check will be bespoke to each turbine's specific EHM and SCADA software architecture however it would be expected that all turbine EHM and SCADA commissioning would encompass a full remote diagnostic check of the systems in ensuring the following:

a) all sensors / signals were functional
b) all systems being monitored as required (and within operating limits)
c) expected levels of data generation were being realised
d) all limits were active and exceedance alarms armed
e) all interfaces were working correctly and that the SCADA system was fully operational in data being collected and stored at the correct data-storage location (and was accessible upon demand)

6.8 Clamp System Functional Check

Purpose: The purpose of this check would be to ensure that the clamp / locking mechanism to the support structure is fully functional and retains autonomous operation in the event of power / grid loss – it is expected that this test would be performed as an integral part of the deployment process.

Check: This check would be bespoke to each turbine's specific support-structure clamping / locking mechanism however would be expected to ensure that the clamp / locking mechanism was operating as per design intent. E.g.

a) All clamp / locking mechanism sensors and signals were fully functional in providing appropriate feedback
b) Clamp / locking mechanism was able to resist unintentional yawing when fully clamped to support structure
c) Clamp / locking mechanism could be autonomously opened to bearing position (in allowing yaw) and re-closed via turbine control logic without separation from support structure
d) Any logic / software to ensure emergency close of locking mechanism was fully functional

6.9 Turbine Dunk Test / Leak Check

Purpose: The purpose of this check would be to ensure that the turbine remained leak-proof when submerged. It is expected that this would be performed as an integral part of the deployment process by monitoring bilge system sensors and installed cameras.

Check: It is expected that this check would be performed as an integral element of initial deployment by ensuring that the bilge system was active and fully operational in detecting any leaks when the turbine was submerged. In addition, any other appropriate instrumentation or monitoring system (e.g. internal cameras and humidity sensors) should continue to be monitored.

6.10 Vessel Bridge Box Check

Purpose: The purpose of this check would be to ensure that the turbine remained controllable via the vessel bridge box - it is expected that this check would be performed as an integral part of the deployment process.

Check: It is expected that this check would be performed as an integral element of the initial deployment by ensuring that the turbine was controllable via the vessel bridge box during deployment.

6.11 Availability Criteria Check

Purpose: The purpose of this check would be to demonstrate that any contractual reliability criteria had been met during the deployed commissioning phase of the turbine.

Check: Whilst it is to be expected that delivery of a production turbines would include a "demonstration of availability" during the deployed commissioning phase (e.g. the percentage of time when the turbine is ready to operate assuming environmental conditions are within limits to generate), each schedule and the success criteria for passing such a demonstration would be contract specific.