RELIABILITY AS A CRITICAL FACTOR IN THE DEMONSTRATION OF TIDAL TURBINES

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SUMMARY

I. The company

Driving force of the energy transition, 12 years of experience in ocean energy

2008 | D03-30
1st tidal turbine installed in France during 12 months

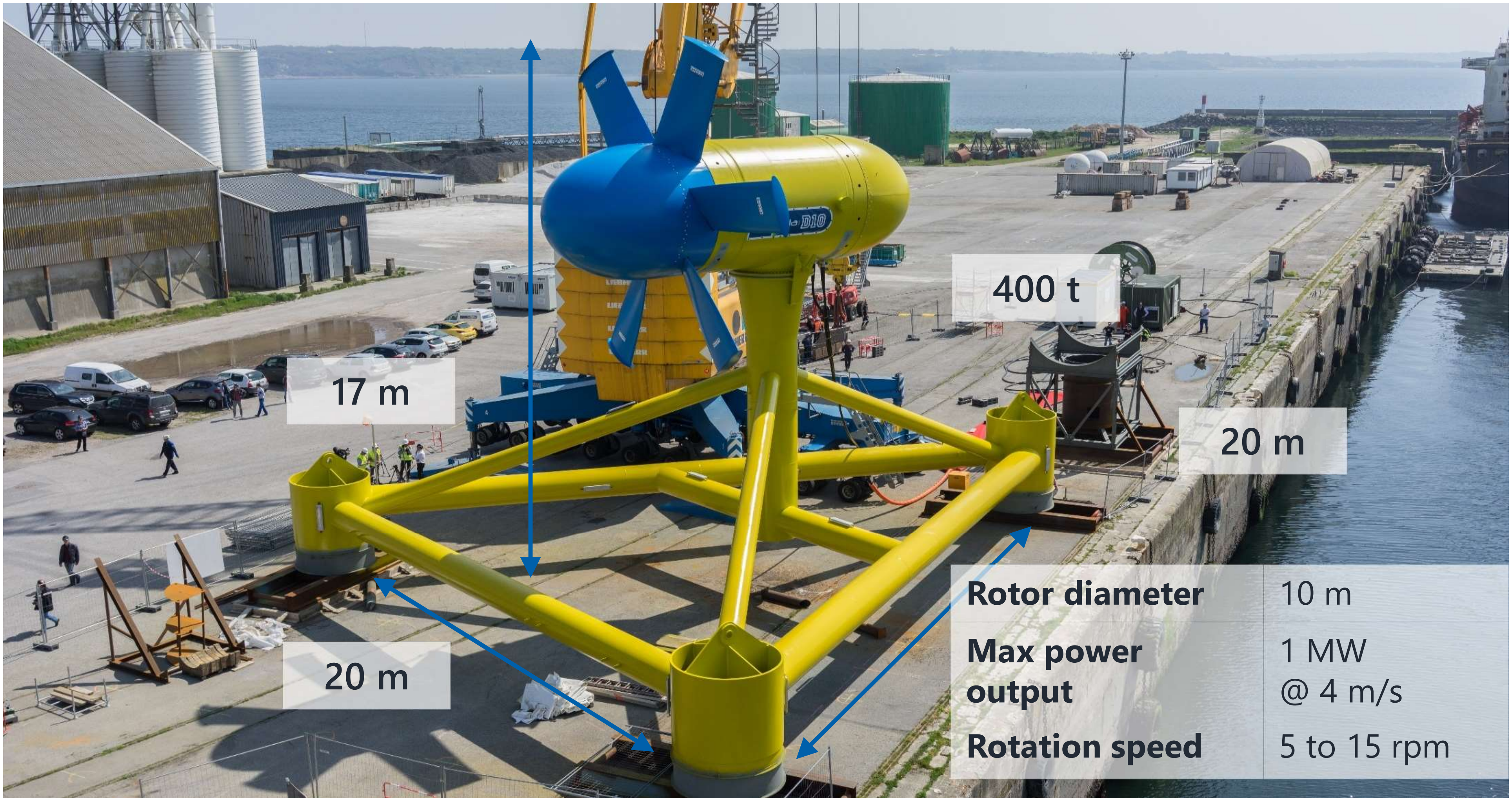
2015 | D10-1000
1st tidal turbine to supply electricity to the French grid

Key facts

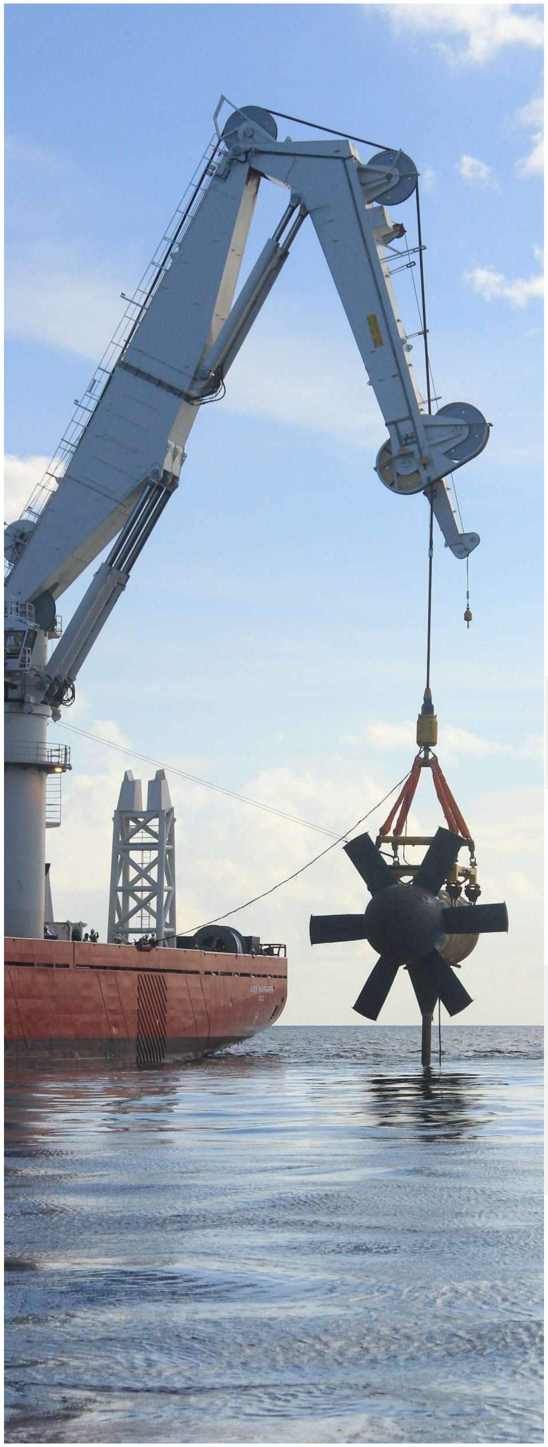
- Created in 2008
- 25 employees
- EPCI (Engineering, Procurement, Construction & Installation)
- ISO9001 certification
- 100% owned subsidiary in Canada (HYDRO-SAB)
- Indonesian consortium (MPS)
- Turnover: €1 million
- Shareholding structure: 25% of industrials, 50% of financials, 20% of founders, 5% of management

II. SABELLA tidal stream technology

D10 demonstrator



Rotor diameter	10 m
Max power output	1 MW @ 4 m/s
Rotation speed	5 to 15 rpm



II. SABELLA tidal stream technology

A cutting-edge technology for a differentiated solution

Direct drive generator with permanent magnets

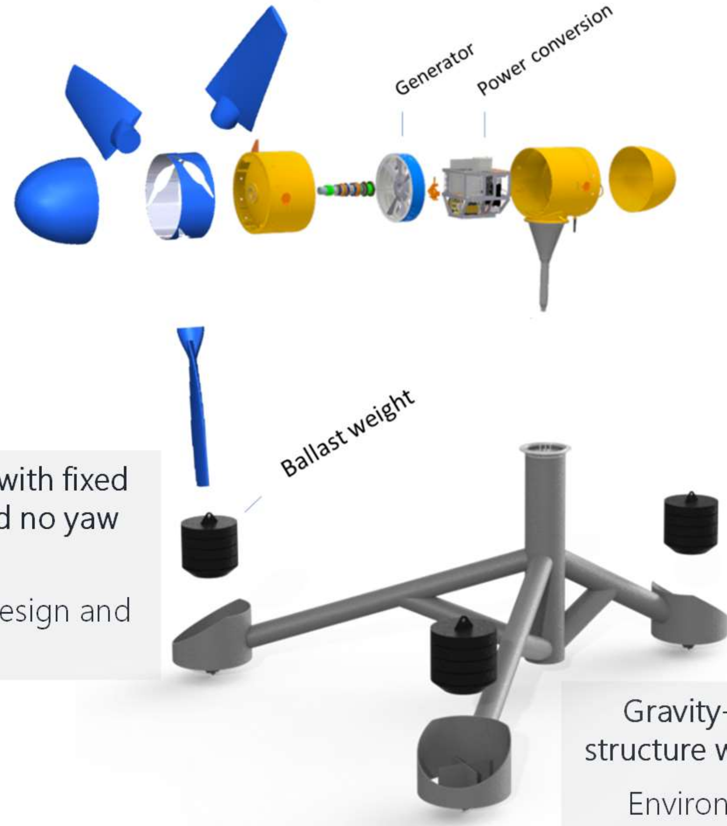
No wearing parts

Onboard conversion chain and transformation with complete redundancy

Increased reliability in case of component failure

Low rotation speed

Marine life friendly



Modular architecture

Installation and O&M costs reduction

Horizontal axis turbine with fixed symmetrical blades and no yaw system

Improve yield, proven design and ruggedness

Gravity-based support structure with ballast weight

Environmental impact

III. Reliability as a critical factor for tidal devices

Why is reliability crucial for tidal energy development?

- **Operation in harsh environment:**
  - high currents,
  - waves
  - unsteady flow,
  - fouling, abrasion....
- **Installed on seabed:**
  - no internal inspection possible, supervision by sensors,
  - no on-site repairs.

- ➢ A minor failure can require the turbine to be retrieved and repaired onshore;
- ➢ The turbine retrieval requires an expensive offshore operation with a DP vessel with a high crane capacity;
- ➢ Few weather windows for offshore operations (during neap tide, with good waves conditions): risk of long downtime for maintenance.

Reliability represents a key factor in the tidal turbine business model, particularly for OPEX (limiting maintenance operations) and revenues (reducing downtime).

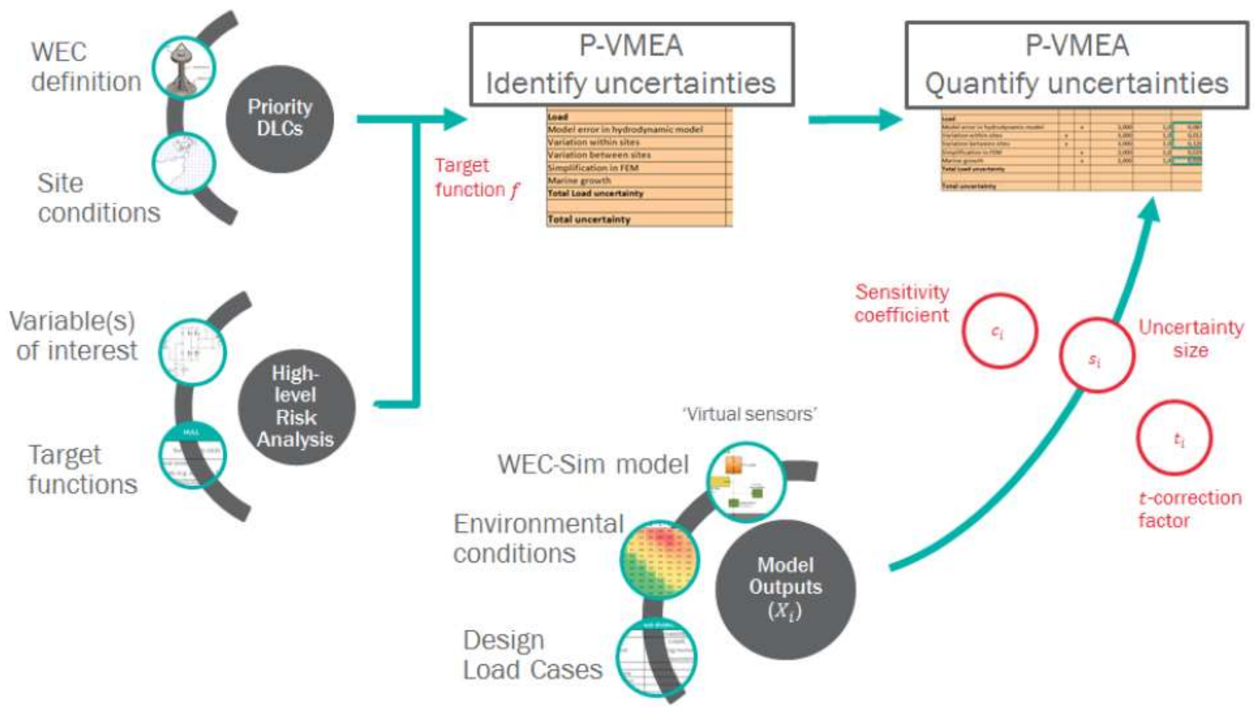
IV. Main R&D projects for reliability improvement

MONITOR : VMEA methodology

VMEA focuses on understanding the influence of uncertainties on a device or component.

There are 7 main steps:

1. Target Function Definition
2. Uncertainty Sources Identification
3. Sensitivity Assessment
4. Uncertainty Size Assessment
5. Total Uncertainty Calculation
6. Reliability and Robustness
7. Improvement Actions



Flow chart depicting integration of different data sources and calculated parameters to a VMEA study.
Atcheson et al, (2019). *Quantification of load uncertainties in the design process of a WEC.* Proc. Of the 13th European Wave and Tidal Energy Conference.

IV. Main R&D projects for reliability improvement

MONITOR : Application of VMEA on blades

Input: Environmental conditions
- ADCP data – TI, TKE, U, waves
- Annual occurrence of wave Hs, Tp (mean, SD)
- Shear profiles
- Annual tidal flow speeds

➢ Histogram of sea states

Input: Device details
- Operating curve (TSR, speed at tidal flows)
- Estimated annual starts/stops

➢ Operating speed in a given sea state

Input: Component geometry
- Blade geometry (cross sectional areas)
- Elastic modulus (for calc from strain gauges)

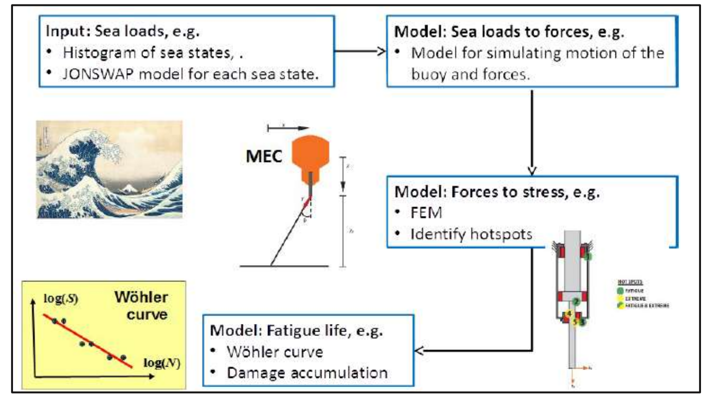
Input: Component properties
- Ultimate tensile strength
- Yield strength
- S-N curve (m-value)
- Design life

Model: Load history
- BEMT/CFD – using sea state histogram to define operating states
- Data from blade strain gauges

➢ Loading force-time for blade for each sea state

Model: Forces/strain to stress
- Convert force to stresses (BEMT)
- Convert strain to stresses (SGs)
- Verify blade root is highest stressed area

Model: Fatigue behaviour
- Damage accumulation (based on time spent in each sea state, using rainflow counting)
- Damage equivalent
- Wohler curve



Example of stages to calculate target function for a MEC
Riasor 2016 – Reliability Guidance for Marine Energy Converters

Uncertainties are then identified based on this target function and the associated models.

Size and sensitivity for each uncertainty is calculated based on the methods presented earlier.

IV. Main R&D projects for reliability improvement

RealTide : FMEA and RAM assessment

Failure Modes Effect Analysis (FMEA)

System/Sub-systems/ Assembly / Equipment → Equipment Functions → Failure Modes / Root Causes → Criticality (LxS) →

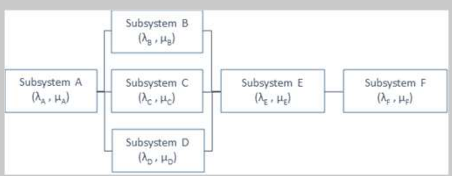
Results
- List of Equipt FM
- Design improvements
- Monitoring Activities.

Inputs:
- Literature on Tidal Turbines Design
- Wind Turbine similarities
- Experience from partners on tidal turbine specificities

Inputs:
- Literature on Tidal Turbines Reliability
- Reliability Databases
- Experience from partners on rotor failures
- Experience from partners on wind turbines

Inputs:
- Maintenance Philosophy
- Spare parts Philosophy
- Operational profile

Reliability, Availabilty, Maintainability (RAM)



Reliability Bloc Diagram

Sub-system	Assembly	RAM Component	Failure rate (/year)	MTTR (Hours) Major	MTTR (Hours) Minor	MTTR (Hours) Trivial	Production Impact
Hydrodynamic System	Nacelle	**Nacelle Body**	1.13%	1.69%	0.14%	0.01%	100%
	Rotor	**Blades**	8.50%	1.69%	0.18%	0.02%	100%
		Pitch System	17.07%	1.21%	0.16%	0.01%	100%
	Yaw system	**Yaw system**	11.33%	1.69%	0.13%	0.01%	50%

MTTF & MTTR data

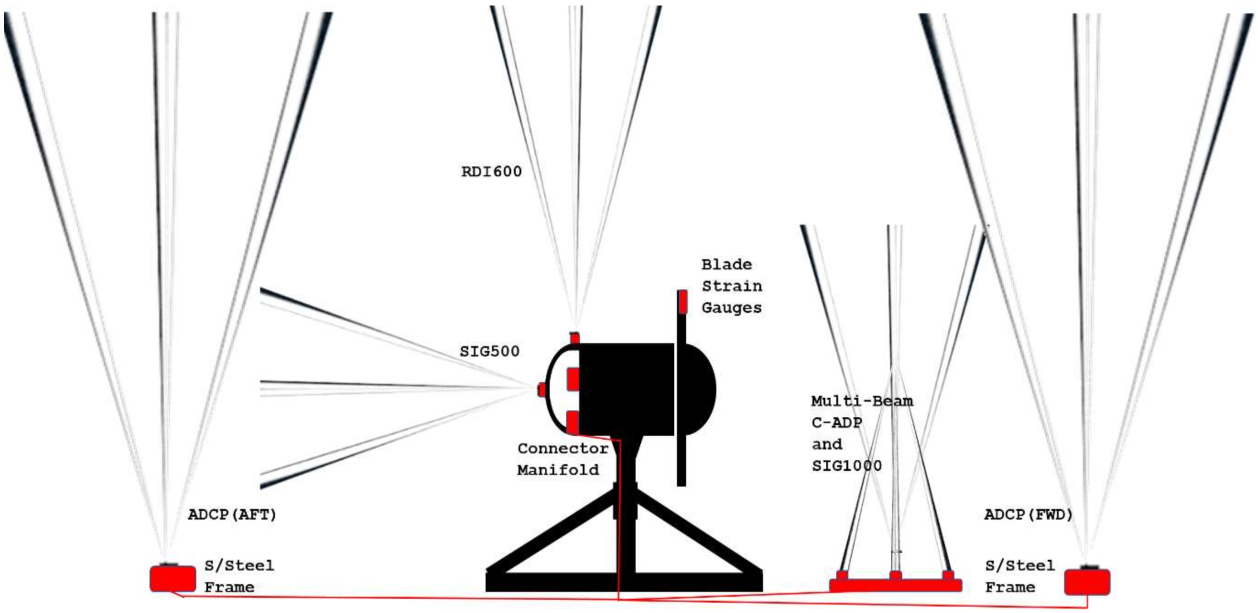
Suitable weather windows

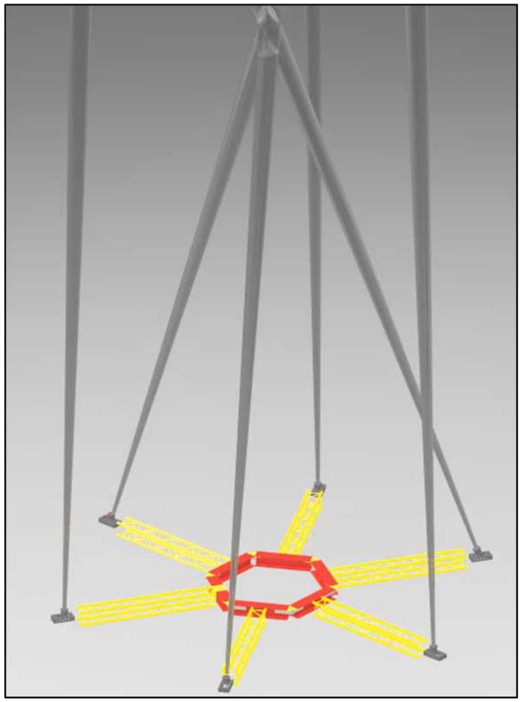
RAM modeling Monte Carlo simulation →

Results:
- System availability
- Global system reliability
- List of Critical Components
- Design improvements
- Equipment failures/repairs

IV. Main R&D projects for reliability improvement

RealTide : high resolution flow characterisation





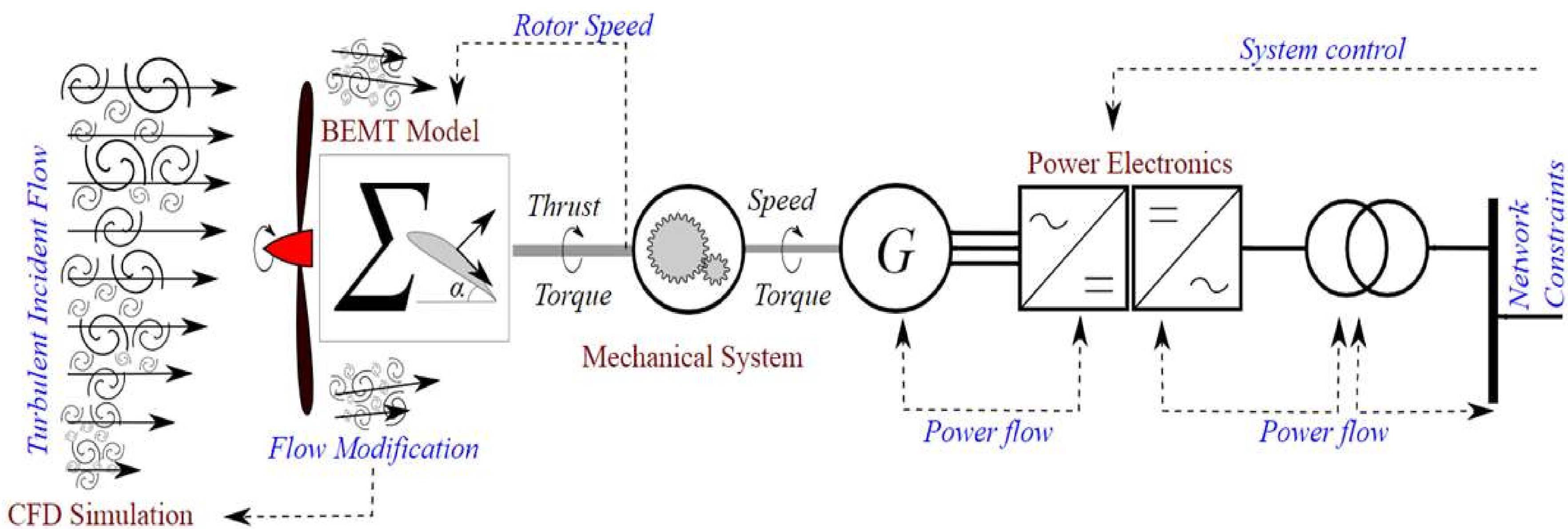
- focus on spatial variation of TEC flow metrics which play an important role in Resource Assessment
- Development of a next generation sensor for the advanced measurement of fluid behaviour in the vicinity of marine renewable energy devices, rotor plane mapping.

➢ Characterise the influence of unsteady flow on torque variation and on load fluctuation on blades

➢ Refine mission profiles for fatigue assessment

IV. Main R&D projects for reliability improvement

RealTide : Tide-to wire modeling

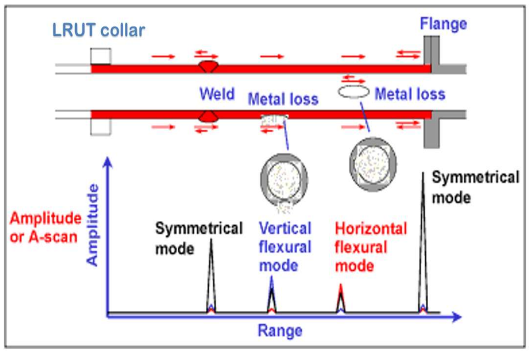


- Complete modeling of PTO and power conversion, using realistic turbulent incident flow as input and a BEMt code
- ➢ generator and convertor stress analysis
- ➢ Definition of mission profile for electrical component under realistic conditions to determine lifespan with suppliers and realise accelerated life testing

IV. Main R&D projects for reliability improvement

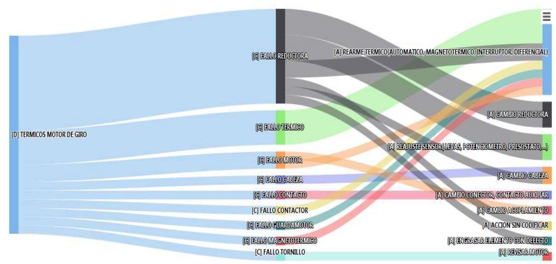
RealTide : Condition Based Monitoring

Adapted monitoring technique



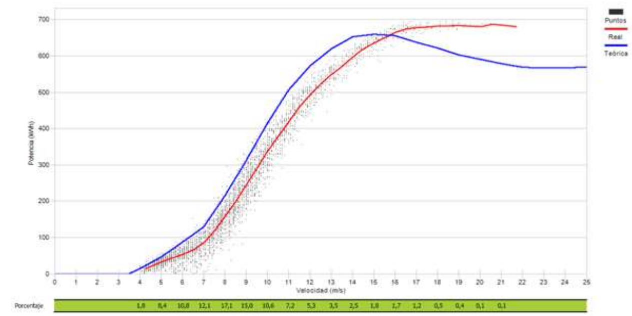
Define the right technique to measure the critical parameter on critical components (pressure, temperature, vibrations, acoustic emission, current signal, ultrasound propagation…)

Intelligent SCADA analysis



Detect the failure by measuring changes in the monitored variable over long periods

Model based estimation (Power Curve Control)



Detect the failure by comparing the monitored variable with its analogous which has been previously calculated in a model.

- Detection of failure before it occurs
- ➢ Avoid unexpected maintenances and prepare preventive maintenance
- ➢ real-time monitoring of critical parameters, accumulation of data on the real reliability of components and ageing curve

Conclusion

Actual limits / next steps

- **Reliability is a key factor for tidal energy development**

- **Lack of reliability data on tidal turbines : modelling based on failure rates of wind, oil & gas, industrial mechanics.**

- **lack of feedback, need for longer experimentation to have usable data on reliability**

- **Need for subsystem test benches**
  - **to verify predictive models and realise accelerated life testing**
  - **to test machines before installation to reduce operational failures**

Thank you for your attention!

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