# THE DESIGN PROCESS FOR A FLOATING PLATFORM OPERATING IN SHALLOW WATER TIDAL FLOWS WITH VERTICAL AXIS TURBINES

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**SUMMARY**

This paper outlines the design process undertaken to select and develop concepts for a floating platform capable of supporting vertical axis tidal turbines. It details the design work including concept engineering, load case combinations and hydrodynamic analysis. The work reported has focused on the arrangement of multiple turbines on a single platform taking into consideration performance, cost benefit, and operation and maintenance. This paper presents an initial look at the project results and discusses the world wide potential for shallow water, small scale tidal turbine technology.

**INTRODUCTION**

Existing tidal energy solutions are high risk and have high capital costs due to the large size of the turbines and expensive installation operations. Instream Energy Systems (Instream) have been developing a smaller-scale, lower-risk solution that is intended to be cost-effective to install and maintain, and can utilise shallow tidal resources (<15 m deep) unavailable to the current leading technologies. The Instream solution is a surface-based, scalable, vertical-axis hydrokinetic turbine (VAHT) power generation building-block which can be aggregated to operate at larger power plant scales. An Instream turbine installed in a water transfer canal is shown in Figure 1.

The Instream tidal energy device consists of multiple VAHTs mounted on a floating platform, termed a Turbine Deployment Unit (TDU). Due to its relatively small power rating (100 - 200 kW) and floating design, installation of a full-scale TDU and its mooring system can be achieved with a multi-cat vessel with day rates of £2,500 to £5,000 [1]. Large, specialist vessels with day rates of up to £40,000 [2] are typically required for the incumbent tidal technologies.


**FIGURE 1, A 25 KW INSTREAM TURBINE INSTALLED IN THE ROZA CANAL, NEAR YAKIMA, WASHINGTON. THE TURBINE IS SHOWN IN THE RAISED, MAINTENANCE POSITION.**

With Instream's technology, the turbine generators and electrical equipment are mounted above the water with only the turbine rotor submerged, improving ease of access for maintenance and inspection and limiting the need for complex, and often problematic, subsea electrical design. In order to realise the benefits of a floating turbine platform the platform must be suitable for boarding and light maintenance activities in the sea states that it is anticipated that maintenance will be carried out. Part of this project is to analyse the motions of the platform to evaluate its suitability for boarding and maintenance activities and to allow access weather windows to be estimated.

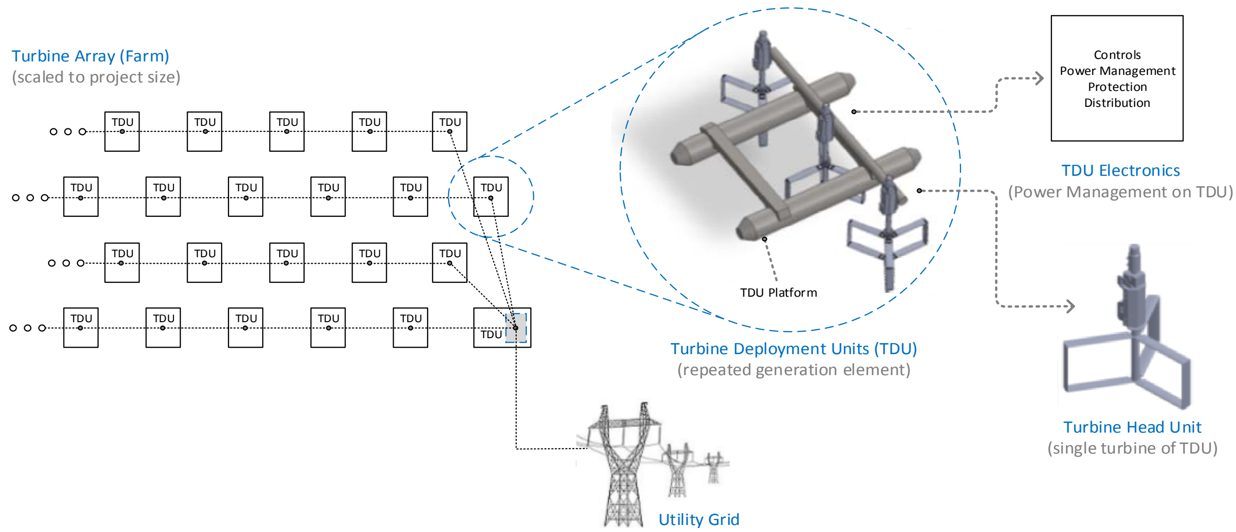


**FIGURE 2, INSTREAM SYSTEM OVERVIEW.**

Instream's patent-pending technology has many advantages, including low installation cost due to the relatively low day rates of the vessels required for installation; simplified surface-mounted design and a maintenance approach which aims to minimise capital and operating costs; and versatile scalability suitable for areas inaccessible to incumbent technology. Instream's advantages result in a flexible, cost-effective solution that can be deployed in expanding markets worldwide, both in marine tidal and inland river and canal applications.

The TDU is designed as a fundamental building-block which can be interconnected in varying quantities and geometric formations depending on the project requirements, site conditions and tidal resource at a given site.

Using this Instream building-block approach, multiple TDUs can be installed to create megawatt-scale tidal arrays. This allows Instream to tailor the generating capacity of an installation to the specific requirements of a project, providing a high degree of project size flexibility and device redundancy, and the ability to build-out in measured increments. These scalable, and low-risk attributes form the basis of the Instream approach as is shown in Figure 2

## DESIGN PROCESS AND PROBLEM DEFINITION

ITPEnergised has developed a proprietary Systems Engineering Process, specifically for the design of wave and tidal devices and their components, termed the 'Design Framework' (see Figure 3). This framework has been developed and refined over a number of marine renewable projects resulting in an effective design process that can be tailored to the project's needs and works alongside industry design codes and certification methods. The framework sets out a structure for moving from concept to final design, considers the design of the entire device holistically so as to minimise conflicts and ensure that important factors (such as installation) are considered throughout the design process.

The Design Framework methodology is a systematic process that helps ensure that all aspects of the design, manufacturing and testing of the component are identified and fulfilled.

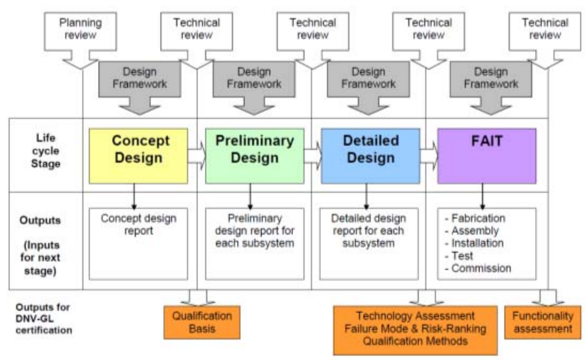


**FIGURE 3, DESIGN FRAMEWORK USED FOR THE TDU CONCEPT DEVELOPMENT.**

## DESIGN ENVIRONMENT

A preliminary UK market potential study tailored to Instream's site requirements has identified 52 potential sites. Of these, 8 sites were shortlisted as being the most promising for Instream to develop, with mean spring peak tidal current speeds ranging from 1.9 to 4.1 m/s. Select environmental conditions from these 8 sites were used to define a representative site for the purpose of the TDU design development. Key parameters of the extreme environmental events at this representative site are as follows:

- Mean water depth: 26 m
- Max. tidal current speed: 3 m/s
- Max. wave height, 50 year return, $H_{MAX,\,50}$ : 6.3 m

- Wave period for $H_{MAX,50}$: range 6.5 to 9.5 s

## CONCEPT COMPARATIVE ANALYSIS

The initial goal of the project was to identify possible TDU solutions to meet the design requirements, and put in place a process for a comparative cost-benefit analysis in order to choose the most viable solution for further development. The optimal number of rotors per TDU platform, and their arrangement on the platform was a key consideration. A number of platform options were identified including mono-hull, catamaran and trimaran designs. TDU concepts with one to five turbines in both linear (perpendicular to flow) and staggered (in offset rows perpendicular to flow) rotor arrangements were considered.

Once this identification process was complete, analysis work to compare and contrast the concepts was undertaken along with some further down-selection as the various concepts became better understood. The analysis included assessment of each TDU concept with regards to:

- **Turbine performance**: Placement of rotors on the same TDU using results of previous computational fluid dynamics (CFD) work on the rotor and rotor arrays carried out by BAE Systems and others to highlight any detrimental effects on turbine performance due to position.
- **Structural design**: Basic steel structure design of hulls and crossbeams to support the rotors and their drive trains. Static structural stress analysis carried out with the use of hand calculations and finite element analysis (FEA) tools to make a comparative estimate of the steel requirements for each concept.
- **Hull design**: Considerations of the platform's buoyancy and stability requirements.
- **Mooring and anchoring system**: High level sizing of gravity anchors and mooring chains.
- **Installation**: Outline of comparative costs, considering the size and mass of the platform and its anchoring system. Vessel capabilities and day rates were used to calculate costs for each concept option.
- **Operations & Maintenance**: Stability of the platform, ease of turbine removal, and operability of the platform with shut down of one or more turbines.
- **Auxiliary equipment**: Suitability of the concept for mounting of electrical equipment, navigation aids, access systems etc.
- **Array considerations**: Suitability of the platform for enabling a high installation density when deployed in arrays.

CFD modelling provided guidance on the effect that proximity and position of adjacent rotors had on overall performance and allowed for a simplification in the analysis whereby closely spaced, perpendicular-to-flow or linear rotor configurations were taken as a fair representation of all rotor configurations, both linear and staggered. Under- hull or thru-hull rotor concepts were eliminated based on the requirement for a simple turbine mounting approach with easy access for turbine installation and removal from above. The remaining TDU concepts were assessed against the defined KPIs. The first output metric used for comparative analysis was CAPEX/MW, the results of which are shown in Figure 4.

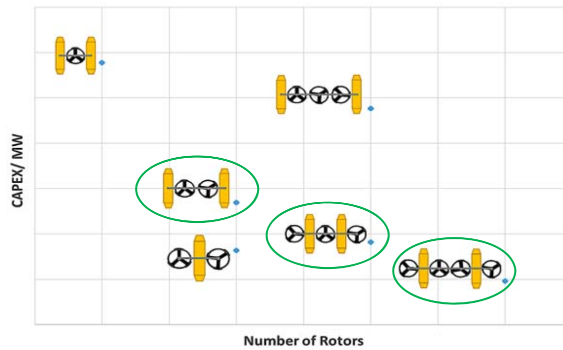


**FIGURE 4, CONCEPT EVALUATION RESULTS, SHOWING CAPEX/MW AGAINST THE NUMBER OF ROTORS FOR VARIOUS CONCEPT DESIGNS**

*(Note: Seven concepts are shown in total here with each concept shown in plan view, not to scale, and comprising hulls in yellow, support structure in grey and rotors in black)*

Estimation of the CAPEX of each TDU concept focused on costs that were likely to be significantly different across the range of concepts. Material costs of the hulls, crossbeam, anchors, and mooring lines were considered in addition to the turbine, drivetrain, and electrical plant costs.

Installation cost estimation included vessel costs for cable, gravity anchor, and TDU installation. The lifting capabilities of installation vessel cranes were looked at in particular detail as step changes in vessel prices were found between 'multicat' vessels, crane barges, and large vessels with Dynamic Positioning capabilities such as Anchor Handling Tug Supply vessels.

Evaluation of the remaining KPIs was carried out and complemented by further assessments of the concepts using tools such as SWOT and Pareto analyses.

Comparative analyses of the concepts concluded with a shortlist of platform options to be taken forward into preliminary design. The three leading concepts which were deemed to most closely align with the pre-defined requirements were shortlisted to be carried forward for in- depth analysis.. These are shown circled in green in Figure 4. Design analysis was undertaken for the two main concepts taken forward using 3D CAD models (in Autodesk Inventor); high-level stress calculations; and hydrodynamic analysis. ProteusDS [3] was used for the hydrodynamic, time domain modelling of the two TDU concepts and model runs were carried out for each of the load cases considered.

## INITIAL MOORING AND ANCHOR SYSTEM DESIGN

In order to enable the hydrodynamic modelling to be carried out an initial mooring system design was required. The mooring system specification, the distribution of buoyancy on the platform, and the connection point of the mooring lines to the platforms were all found to have a significant effect on the loads on the mooring system and gravity anchors. An iterative process was carried out to define a mooring system and platform design that offered a cost effective compromise between platform cost, and mooring and gravity anchor systems cost.

The iterative process included making the following changes:

- Reducing the mooring chain diameter – a lower diameter results in a less stiff mooring line;
- Moving the mooring connection point on the hull from close to the midships to the ends of the hull – reduces peak loads on the mooring line;
- Increasing the platform hull length – reduces peak loads on the mooring line if the mooring connection point is at the ends of the hulls;
- Replacing a short length of steel chain in the mooring line adjacent to the platform with a length of nylon rope – increases mooring line compliance and therefore reduces peak mooring line loads.

The iterative process was carried out by hydrodynamic modelling in ProteusDS for the extreme environmental load case initially identified as resulting in the greatest loads.

A decrease in peak mooring line loads results in a lower design load for the mooring line and anchors. The required mass, and therefore cost, of both components also reduces. Key design changes made in the iterative process and their effect on the mooring and anchor systems masses is shown in Figure 6.

The colour of the dots on the graph represent the platform mass. In order to enable the reduction in mooring and anchor systems masses an increase in platform mass was required, mainly due to making the hulls longer and thinner. The mooring and anchor systems cost saving was greater than the increase in platform cost .

The process led to a 54% reduction in mooring line mass and a 65% reduction in anchor mass over the initial design. Further optimization will be carried out at detailed design.

## LOADS ANALYSIS

Following initial design of the three TDU platforms and mooring systems, hydrodynamic modelling of the concepts was carried out for all of the environmental load cases identified for the representative site. The results of the modelling were used to assess the dynamic behavior and loading of the TDU concepts in response to different environmental inputs.

Post processing of the loads from the hydrodynamic and structural loads modelling was carried out to inform the preliminary design of each TDU structure, thereby allowing capital cost estimates for each concept to be revised, based on updated structure, mooring, and anchoring requirements. A general overview of the final, preliminary design TDU is shown in Figure 5.

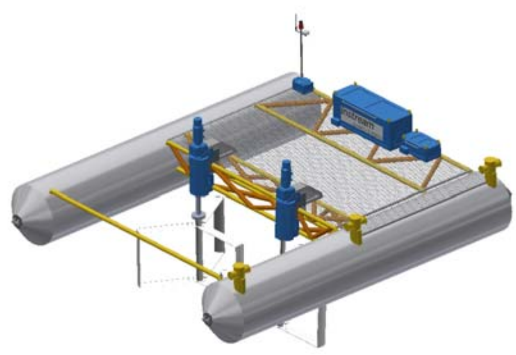

**FIGURE 5, THE GENERAL ASSEMBLY DRAWING OF THE TDU FOLLOWING THE PRELIMINARY DESIGN PROCESS**

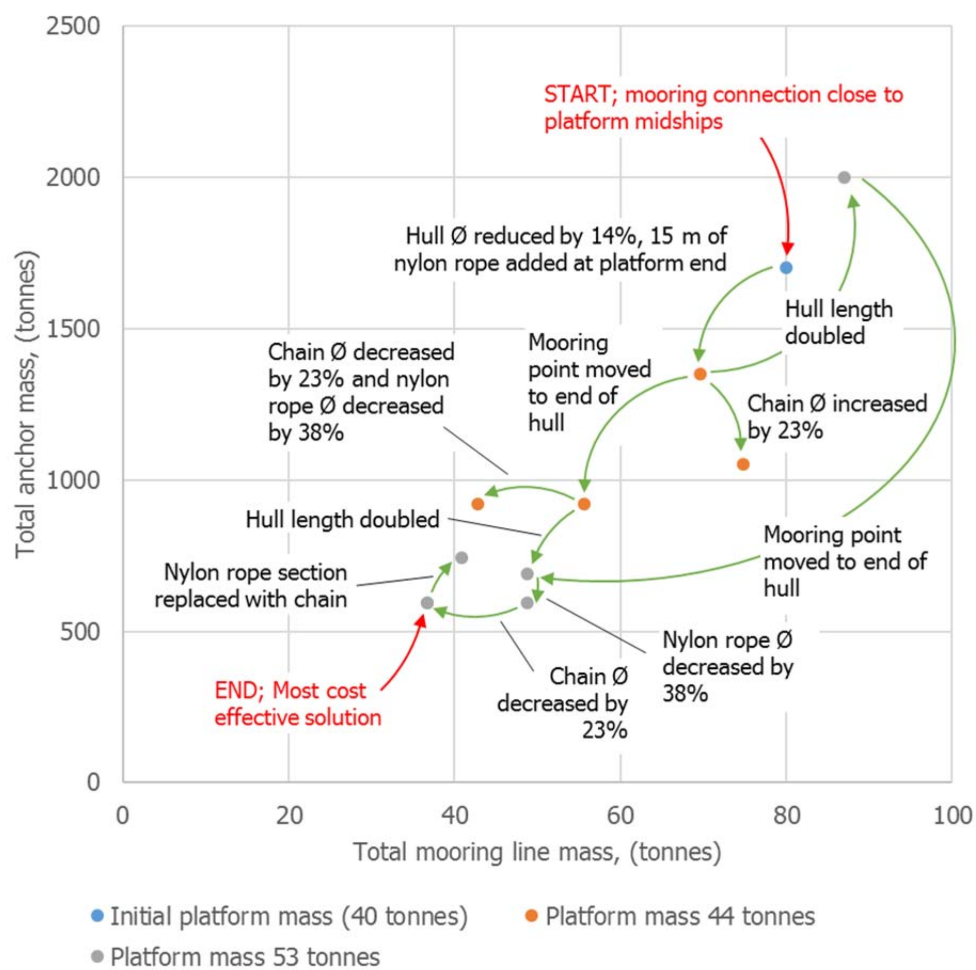


**FIGURE 6, ITERATIVE PROCESS LEADING TO PREFERRED PLATFORM AND MOORING SYSTEM DESIGN**

## CONCLUSIONS

To realise the deployment of Instream's VAHT in shallow water tidal sites, preliminary design work has been carried out for a floating TDU platform in accordance to a defined design framework. Constraints, functional requirements, and a design environment for the TDU have been defined. TDU platform concepts have been developed and compared based on performance, cost, and risk. Concepts short-listed based on initial design criteria were developed further to undergo hydrodynamic modelling and a detailed structural analysis in order to select the most suitable concept to carry forward to future construction and deployment.

This process has resulted in a TDU design that has an optimized cost and performance and turbine rotor configuration in comparison to the original concepts considered at the start of this project.

## ACKNOWLEDGEMENTS

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## REFERENCES

[1] GRS Research Services, http://www.grs-offshore.com/en/any-vessel-any-time/grs-research-services/,

[2] Siem, Daya work out new terms for OSCVs sale, http://www.offshoreenergytoday.com/siem-daya-work-out-new-terms-for-oscvs-sale-one-vessel-cancelled/, accessed June 2016

[3] Dynamic Systems Analysis, Proteus DS http://dsa-ltd.ca/software/proteusds/description/