Methodology for Conceptual Level Design of Tidal In Stream Energy Conversion (TISEC) Power Plants

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1 Introduction and Summary

The purpose of this document is to describe the methodology EPRI will use to establish conceptual designs for both a nominal 500 kW pilot demonstration system as well as a nominal 10 MW commercial-sized system. The conceptual designs will be use as the basis for establishing capital and operating cost parameters as well as identifying critical technical, deployment/recovery and operational issues.

The purpose of the commercial plant design is to study the system, performance, environmental and regulatory issues and evaluate the economics of such a design to determine the techno-economic feasibility of using this technology. If it looks attractive and doable, then we may well want to invest in or influence private investors in developing this clean local renewable resource. The purpose of the pilot plant is a recognition that investors are going to need some actual experiences and reduction of uncertainties before going ahead with a commercial scale plant.

Previously published documents describe the methodologies EPRI will use to estimate the annual power production (Reference 1) and the cost of the plant and the cost of electricity produced (Reference 2).

2 Tidal Power Plant System Outline

An in stream tidal energy conversion (TISEC) power system consists of five (5) subsystems as depicted below; 1) tidal flow energy conversion device, 2) mooring, 3) power transmission, 4) grid interconnection, 5) remote communication, command and control link.

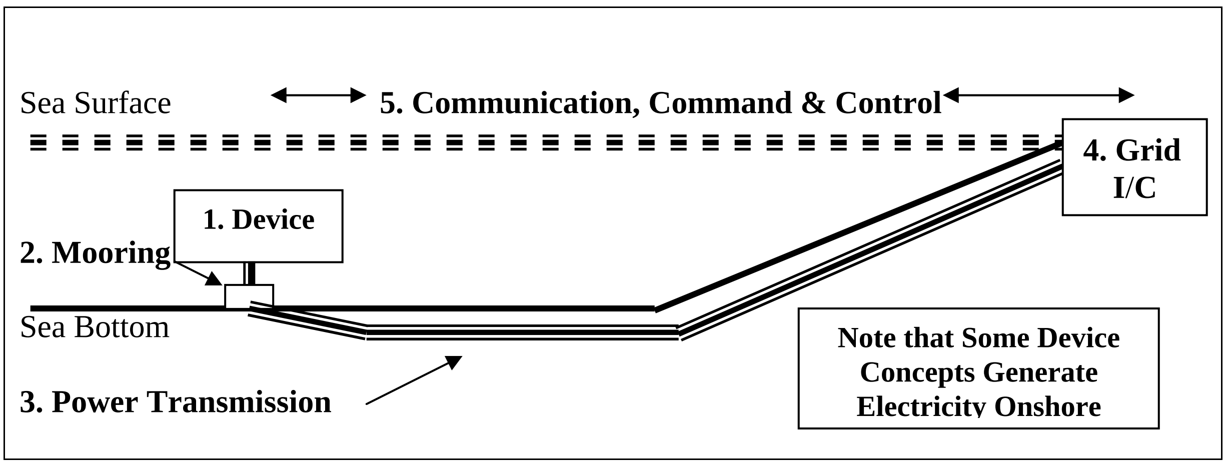

Figure 1   Tidal In Stream Energy Conversion (TISEC) Power Plant System

TISEC devices can be deployed in a modular fashion, similar to a wind farm. Many TISEC devices are under development by different manufacturers with many different technical approaches. These include horizontal axis and vertical axis turbines and venturi-type systems. In addition to these basic device classes, there are hybrid systems. Key considerations in evaluating TISEC devices are their power-train configuration (electromechanical system) and how it can be accessed for operation and maintenance purposes. While many tasks can be accomplished using remote-monitoring systems to determine system failure, physical intervention remains a key criterion to carry out routine maintenance tasks.

In order to calculate the maximum size of the TISEC system or the total extractable power, the available total power in the tidal passage must be reduced by whichever of the following two adjustments is the greater:

1. To reduce the cross-sectional area allowing for clearance depth both at the top and the bottom of the channel (assume _ meters from mean low tide level as required by local navigation clearance requirements). Calculate the percentage of the area eliminated as compared to the total cross-sectional area.
2. An extraction factor to assure no economic or environmental effects (assume a range of 10% (see Ref 3) to 20% (see Ref 4))

While the mode of extraction sets the primary limits on how the primary in-stream energy is being converted into mechanical and electrical power, probably the more important aspect from a cost, installation and operational perspective is how the device is moored to the ocean-floor. Looking at various foundation types, a lot can be learned from the offshore sector and more particular from the offshore wind industry. The illustration below shows the main foundation types for offshore wind-turbines which are; monopile, gravity base, suction cup and tri-pod foundations. In addition, a moored device is shown.

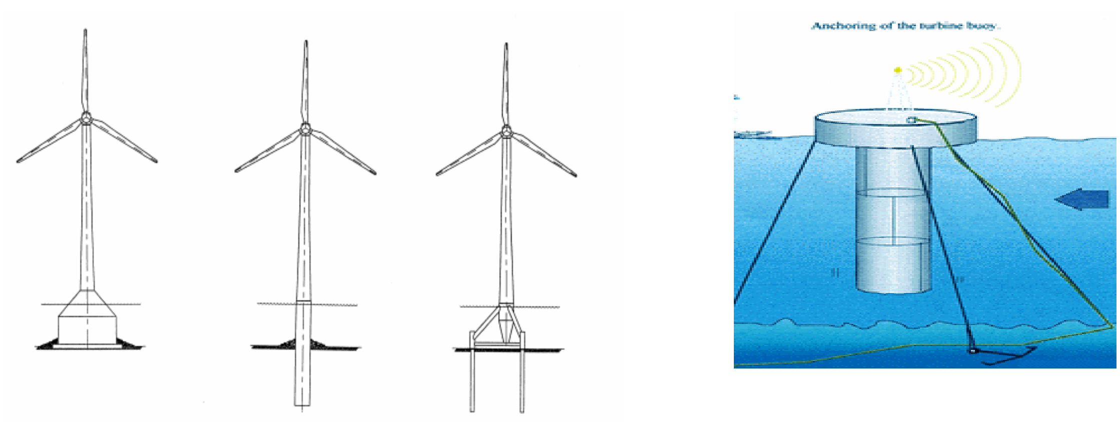

Figure 1. TISEC Device Foundation Types

The primary factors, which drive the choice of the foundation for a particular site are the soil condition (gravel, rock, sand or silt), water depth, erosion because of high currents and loading conditions. In addition, environmental impacts need to be considered. The following is outlining some of the foundation types and their associated primary concerns.

This is by no means a complete list as there are many type of hybrid configuration available, but should provide an outline of the primary types.

Piled foundation type: A piled foundation typically uses a monopole on which the turbine is mounted. The offshore industry has extensive experience with these kind of piles. A pile is easiest and most cost effectively installed in a soft substrate such as silt or sand by use of a vibratory hammer. Gravel or large rocks can complicate the procedure significantly and increase associated costs. Monopiles can readily be drilled into hard substrates. With loose materials, a sleeve is introduced above the drill to prevent the hole walls from collapsing. Pile size and material (concrete or steel) will drive the choice of installation procedure. An adaptation from the basic monopole foundation is a tripod, which is supported by monopiles. The illustration below shows the seabed/pile interaction, which can be modeled by a number of non-linear springs. The illustration shows a simulation of the interaction between a monopile and the soil.

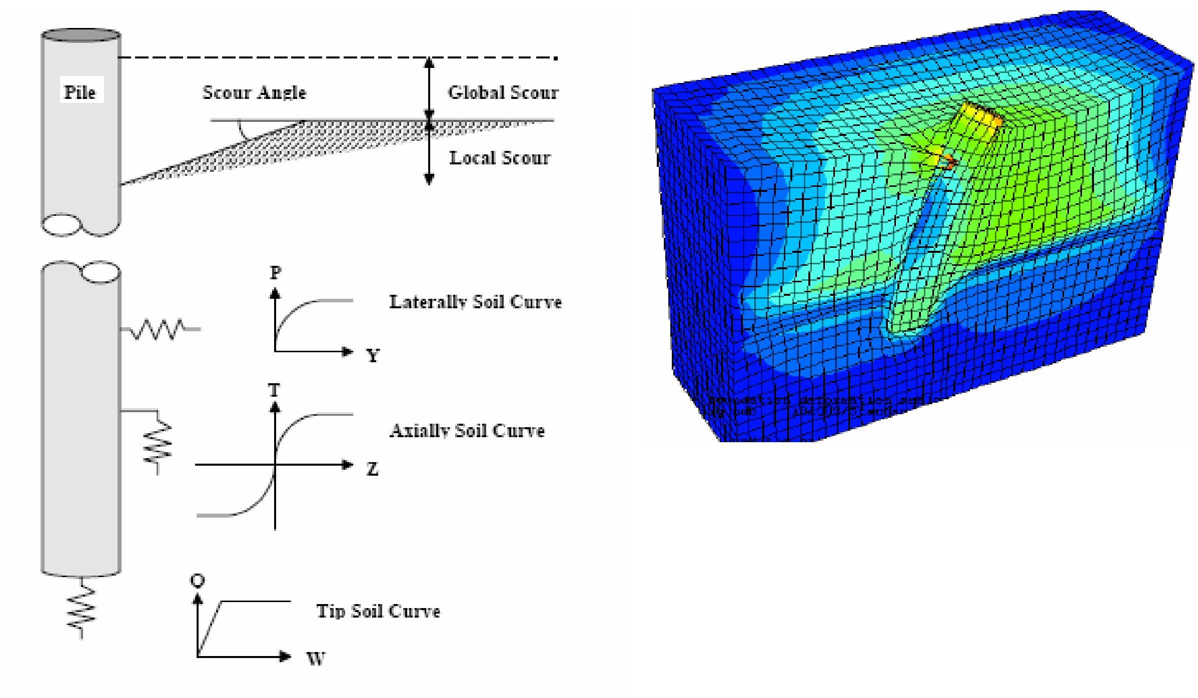

Figure 2 Modeling the Seabed Pile Interaction and a Typical Simulation Output

Gravity Foundation: A gravity foundation consists typically of a heavy block of concrete, which sits on the ocean floor. The turbine is mounted directly on this gravity block. The gravity foundation is designed to avoid tensile loads between the support structure and the seabed. By providing sufficient dead load the foundation stabilizes the structure under overturning moments from tidal currents, waves, and/or ice. A critical issue with gravity foundation is scour, that can occur in tidal streams. Scour is the erosion process where seabed material is eroded and removed due to the hydraulic impact from currents and/or waves and needs to be accounted for in the design process. This is especially true if the installation locations seabed consists of soft sediments. Scour protection is typically required for such foundations such as laying down mats or dumping large rocks. Scour is the erosion process where seabed material is eroded and removed due to the hydraulic impact from currents and/or waves and needs to be accounted for in the design process. The presence of an obstruction on the seabed causes the flow to accelerate around it which in turn results in a scour hole surrounding the object

Suction-cup based foundation: A rather novel concept is the use of suction cups on a tri-pod foundation. Instead of piles, three suction cups are supporting the structure. Suction cups are steel-drums, which are open to the seabed. Installation of these suction cups is achieved by removing fluid from the drums (i.e. creating suction). The weight of the water column on top of these drums will drive them into the seabed. Suction cups require sufficient water depth to establish a large enough pressure difference to drive them into the seabed. Because suction-based foundations do not penetrate as deep as driven piles, scour is an important consideration in the design process. If the seabed material is soft enough to allow suction caps to cut into it, then it seems fairly certain to be subject to serious scour. In any case most locations with strong currents will not have a soft seabed and suction caps will not work on a rocky seabed. The following illustration shows the cross-section of a single suction cup.

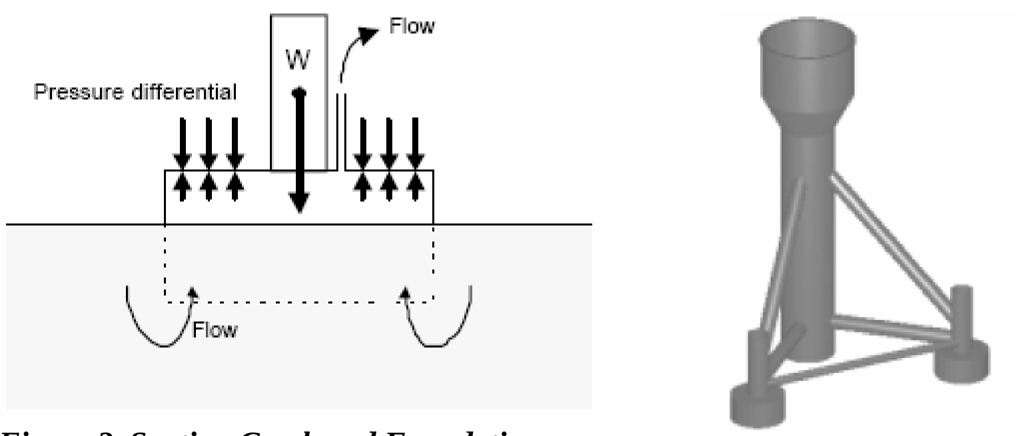

Figure 3 Suction Cup based Foundation

Moored: Slack moored devices float in mid-water. They are moored by multiple cables and/or chains to the seabed. Anchor-types used for these device-types depend on the local soil conditions. The most frequently used in the offshore industry are dead-weight anchors and embedment anchors. An illustration of a moored TISEC device is shown below.

A major concern with moorings is the dynamic effects due to vortex shedding and wave motion which may result in fretting or wear and tear -

Most manufacturers have generator, variable speed converter or grid-synchronizer and step-up transformer located on the device itself. This allows the system to be connected to a common ac transmission cable, which allows the power transmission to shore. Figure 5 below shows a typical outline of such a configuration. Transmission voltage at the power levels envisioned for both demonstration and commercial plant will likely be at a distribution level (i.e. 12-34.5kV).

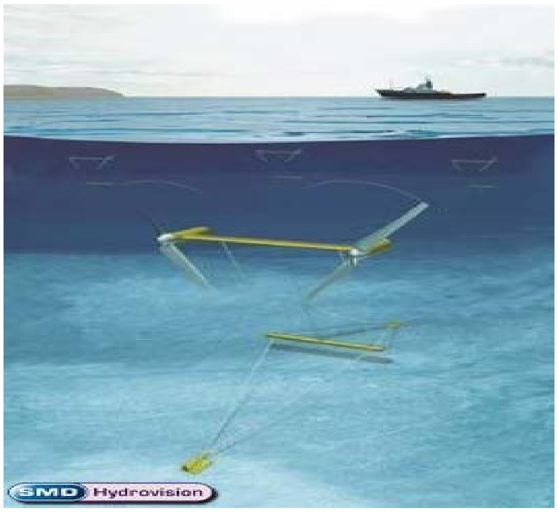

Figure 4 Moored TISEC Device

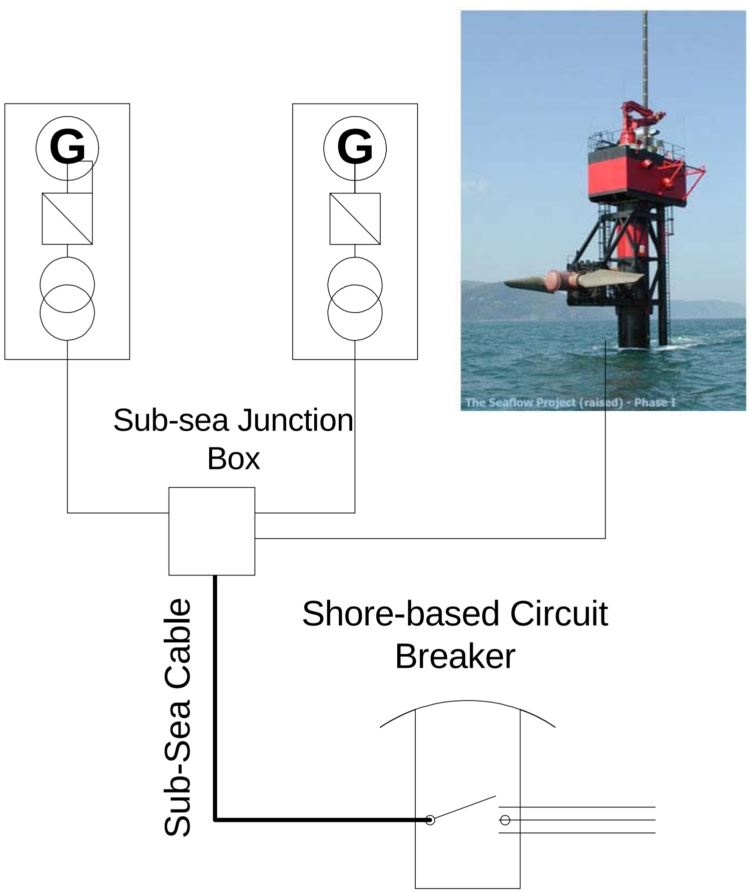

Figure 5. TISEC System Electrical Interconnection Diagram

3 Methodology Outline

The methodology that EPRI will use to develop realistic conceptual reference designs follows a process to reduce cost uncertainties and to form a solid foundation for further detailed design efforts.

The process consists of the following steps:

1. Create project plans for each site outlining the process from initial site assessment activities through deployment and operation, including realistic timetables, resource requirements etc.

2. Establish cost parameters for each site, taking into consideration realistic site constraints such as available equipment, distance to shore, grid interconnection, available port infrastructure, weather windows etc.

3. Based on site specific tidal data, estimate the annual power production of the device in its location. The methodology used is in principal described in Reference 1.

4. Develop the capital cost and cost of electricity estimate for both a small demonstration pilot plant and a commercial plant using the methodology described in Reference 2.

Wherever possible the methodology will use parametric models, which will enable EPRI to carry out basic cost optimization, evaluate alternative tidal farm configurations and identify critical economic parameters.

Driving consideration for the pilot and the commercial plants are slightly different in that:

- The pilot plant design is driven by providing a least-cost option. This might lead to the selection of a site in closer proximity to shore and existing infrastructure, where the tidal climate is not ideal in order to lower capitals expenditures. Leveraging of existing easements in place such as an existing landfall, local support to provide infrastructure components etc. will be a key driver in the system design.

- The commercial power plant is driven by overall economic considerations in order to yield the lowest cost of generated electricity ($/kWh). .

4 Project Outline

The process, tasks and associated timeframes required for the a Phase III Construction and a Phase IV Operation will be outlined in form of a project plan. This will assist in the establishment of clear resource requirements and associated cost centers. These project plans will vary depending on site and device selection, but could include some of the following elements with associated constraints:

- Procurement
- Fabrication
- Assembly
- Transit between fabrication/assembly site and Coastal staging site
- Installation of moorings and transmission cable
- Testing and Commissioning
- Deployment of TISEC Device
- Operation and Maintenance Activities
- Weather windows
- Operation & Maintenance

All elements of the lifecycle cost of this plant will be considered except of decommissioning. Decommissioning will have only a minimal impact on the levelized cost of electricity as the cost is incurred at the end of the project cycle.

This project plan will vary depending on site and technology specific considerations. Where possible, driving assumptions will be used from the manufacturer and if these raise concerns, EPRI will come up with its own assumptions based on related projects.

5 Cost Centers

Generic cost centers were previously identified in the cost assessment methodology (Reference2). These cost centers are used as a basis in coming up with total capital requirements and O&M cost. Depending on the specific site and device selection made by the individual states, changes will be made where necessary in order to accommodate for different requirements. Where possible, such cost will be taken from the manufacturer and cross checked with local estimates to reduce uncertainties. The cost estimates will be modeled parametrically where it makes sense in order to provide a means to evaluate different configuration options. A key focus area will be on the reduction of cost uncertainties as the experience gained by the EPRI project team showed clearly that cost uncertainties are significant in this early stage industry and there is a need to reduce these uncertainties to a point where reasonable cost predictions are possible.

6 Estimate Power Production

The methodology to estimate power production is outlined in a previous document (Reference1). In this task, EPRI will go a step further to validate the device performance and consider site specific impacts of the site choice on device performance.

7 Costing Model

As outlined in Reference 2, cost learning curves will be applied on the 10MW reference plant in order to come up with an estimate on the future competitiveness of TISEC power. This data can then be used to compare the future competitiveness of tidal power to other renewable generation options such as wind energy generation.
Understanding that the costing model will only be as good as the underlying data the focus and attention will be given to the reduction of uncertainties in cost and performance

estimates. The basic performance and costing parameters can be fed into other performance and costing model, thus allowing other entities to come up with their own estimates on cost of electricity ($/kWh).

8 Standards and Assumptions

Offshore conditions are harsh and require specialized equipment to carry out operation and maintenance activities. Cost of these operation and maintenance activities can become a dominant factor in the overall economic picture.

No accepted standards exist for the construction, operation and maintenance of TISEC devices. A draft standard for tidal turbines has been produced by Germanischer Lloyd. Related standards are found in the offshore oil & gas industry, which has a significant amount of experience in this field and developed standards for stationary offshore installations.

Costs for mobilizing and operating offshore equipment such as offshore handler tugs will be estimated based on related offshore projects. Costing data will be verified where possible by local offshore operators that have experience with similar projects. Operational weather windows will be estimated based on local wave data and cross checked with local operators.

Grid Interconnection standards and common practices will be adopted from the electric power industry. IEEE 1547 is likely the applicable standard to interconnect the offshore wave power plant with the electric grid and will be used for this study.

Standards for Performance and cost analysis have been previously established by the EPRI team (Reference 1 and Reference 2).

9 References

1. EPRI – TP - 001 NA, "Guidelines for Preliminary Estimation of Power Production by Tidal In Stream Energy Conversion (TISEC) Devices" draft published April 30, 2005

2. EPRI-TP-002-NA "Economic Assessment Methodology for Tidal In Stream Energy Conversion(TISEC) Devices, 2nd draft published July 15, 2005

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4. Black & Veatch Group, 2004. "UK, Europe, and Global Tidal Energy Resource Assessment." Marine Energy Challenge Report No. 107799/D/2100/05/1. London: Carbon Trust.