Photo Credit: Elisa Obermann

3 TIDAL POWER EXTRACTION DEVICES



3 - TIDAL POWER EXTRACTION DEVICES

Authors: Dr. Sue Molloy and James Taylor, P.Eng.

WHAT DOES THIS MODULE COVER?

This module outlines the basics of the technology and infrastructure for tidal energy devices. The module serves as a very general primer on the three main types of tidal energy devices and the transmission systems needed to get energy generated from tidal devices to shore.

The module will cover the following main areas:

- Types of turbines developed to date,
- Mooring types,
- Considerations related to the installation and maintenance of turbines, and
- Power systems and components including cabling to shore.

3.0 - INTRODUCTION

Tidal turbines are in the early stage of development. Currently, developers are focusing on getting devices operational and the overall development costs reduced. Optimization of devices is further down the line. As a result of this, the configuration of the devices that are currently being tested and demonstrated may look very different from the devices we will see being installed five years from now.

This section will focus on what can be seen as the primary configurations currently being considered by developers and the corresponding structural considerations that need to be made to install some of these designs (Figure 3-1). The installation, maintenance, and cabling are also addressed. It is important to note that these areas are a large focus of research and development and are the source of the highest costs in the commissioning of tidal power today.



Figure 3-1: Schematic of Vertical Axis Turbine (Khan et al. 2009)

3.1 - TURBINES

Tidal turbines are being called by a number of names, including:

- Tidal power extraction devices (TPED),
- Tidal In Stream Energy Converters (TISEC),
- Marine Energy Converters (MEC), and
- Marine Hydrokinetic (MHK) turbines.

However, the International Electrotechnical Commission (2012) has chosen TEC – Tidal Energy Converter and turbine as official terms. In Nova Scotia, tidal devices are often referred to as TISEC. In this module, devices will simply be referred to as turbines.

Turbines rotate in tidal currents of typically 2m/s-- 4m/s (metres/second) (4-8 knots). This rotational energy turns an axle that creates electrical energy through a generator. That electrical energy is then used to provide power for a specific user or is added to the central power grid. The amount of power generated is directly related to the speed and flow rate of the current, where speed is how fast the current travels and the flow is the volume of water that passes a location in a given time. The high current speeds in some regions the Bay of Fundy (more than 5m/s) present developers with both a unique opportunity and a formidable challenge.

Turbines do not use fossil fuels and few require power to initiate rotation; in most cases, the tidal current is enough to begin the rotation of the turbine. Some vertical designs require a small amount of power to give them an initial push (Kahn et al., 2009).

Turbines in development today are being designed in consideration of the environment in which they will operate. Fish guards, protection screens, speed controls, and more are being used to mitigate the chances of fish strikes, to reduce the impact the turbine has on the environment, and to reduce the impact the environment has on the turbine.

A general attitude in the tidal industry right now is that turbine designs need to be kept simple. Fewer parts in the design mean less maintenance will be required over the life of a turbine and a simple design enhances the ability of the device to work in the marine environment. The high current speeds of the Bay of Fundy (more than 5m/s) offer developers both a unique opportunity and formidable challenge.



Some questions currently facing designers include:

- What is the marine environment like at the installation site?
- How will the turbine be installed?
- How accessible will the turbine be for maintenance?
- How long will the turbine last before maintenance is required?
- What kind of maintenance can be expected?
- How much time will there be to access the turbine at slack tide?
- Should the turbine be installed on the sea floor or floated at the surface?
- How will the geological marine environment affect the turbine and vice versa?

As projects progress, these questions get asked over and over again, and each new marine environment requires a new set of answers. At present, turbines need to be customized for an environment as there are no "one size fits all" turbines at the moment. Some solutions to these types of questions have been successful in one location and found to be completely inappropriate in others. For example, the Bay of Fundy has approximately 20 minutes of slack tide and very high current speeds, which makes drilling to install concrete piles unattractive. However, piles have been used successfully to support many turbines in the ocean around the European Marine Energy Centre Test Centre in the Orkney Islands in Scotland, where the currents are somewhat slower.

3.2 - TYPES OF TIDAL TURBINES

There are three main configurations or styles of tidal turbines; within those configurations, there are many designs (Kahn et al., 2009). Horizontal and vertical axes are the most popular configurations and right now, horizontal axis turbines are the dominant style with developers. Horizontal axis turbines look similar to propellers and wind turbines, but the blades rotate at much slower rates. The configuration of a vertical axis turbine is like an eggbeater. The third main style is the crossflow turbine, which has a horizontal axis that is perpendicular to the flow; the configuration is like a push-style lawnmower.

VIGNETTE: SEAGEN

The longest commercially operating tidal turbine is the SeaGen turbine located in Strangford Lough in Northern Ireland (http://www. seageneration.co.uk). It is a horizontal axis turbine. At maximum capacity, SeaGen generates 1.2MW of electricity.





3.2.1 - HORIZONTAL AXIS TURBINES

When a turbine has a horizontal axis, the axis of rotation is designed to be parallel or slightly off-parallel to the flow of the water (Figure 3-2). The blades that are used are lift or drag type blades. These are the blades used most often in propellers and wind turbines. The profile or shape of the blade and the orientation of the blade can be manipulated to maximize the power from the incoming flow. This means the blades are turned and shaped to get the most power out of the flow when it is directed into the turbine.

Some blades are designed to operate in both the incoming (flood) and outgoing (ebb) tidal flows and some blades are designed to operate in more turbulent flows. Most horizontal axis turbines work best when flow is in one direction and has very little turbulence.

Finally, open centre turbines are shaftless and have the blades connected to the outer rotating rim to allow current flow through a large, centered "hole." Open centre turbines are considered to be another style of horizontal turbine and there is considerable interest in applying this particular style of device in the Bay of Fundy.



(c) Non-submerged Generator (d) Submerged Generator

Figure 3-2: Horizontal Axis Turbines (Kahn et al. 2009)

VIGNETTE: CLEAN CURRENT

Open centre turbines are being considered for operation in the Bay of Fundy. One design is being developed by Clean Current, a Canadian company based in British Columbia.



3.2.2 - VERTICAL AXIS TURBINES

Vertical axis turbines have an axis of rotation that is perpendicular to the flow of water. This means the axle around which the blades rotate is vertical at 90° to the water flow direction. Again, the blades are lift or drag type blades and the turbines often resemble a weather vane or eggbeater. Some of the blades used in vertical axis turbines are designed to catch the water as it flows through the turbine and use that energy to turn the axle. The Savonius design, with the "catch-flow" style of blade, is inefficient but is valuable in slow flows (Figure 3-3). The Savonius style has been used in combination with other styles, such as the Darrieus, in order to get the rotation of the more efficient blade styles started. Vertical axis turbines frequently need to be started by an alternative power or blade source when the flow speed drops below a minimum level (Kahn et al., 2009).



Figure 3-3: Vertical Axis Turbines (Kahn et al. 2009)

42



3.2.3 - CROSS FLOW TURBINES

Cross flow turbines have the axis of rotation across the flow of water, parallel to the water surface. Lift or drag type blades are also used in this style of turbine (Figure 3-4). This style of turbine is less commonly seen under development, but there are small-scale tidal power projects where it is being used. Fundy Tidal Inc. is considering a cross flow turbine for a project in the Bay of Fundy.



Figure 3-4 Cross Flow Turbine (TidGen) Source: http://www.orpc.co/orpcpowersystem_tidgenpowersystem.aspx

3.3 - FLOW

The flow of the water into the turbine may need to be directed if the efficiency of the blades is significantly impacted by the flow direction or if the turbine is located at a particularly turbulent site. The general term for these flow directors is "duct" or "diffuser" (Figure 3-5). At the present time, ducts are more commonly seen on vertical axis turbines than horizontal axis turbines. The additional maintenance involved with a duct will depend on the style of duct chosen. The curvilinear duct, for example, has fewer parts than the multiple hydrofoil diffuser. This type of duct is in line with current thinking in turbine design that simple devices are more appropriate for the ocean environment (Kahn et al., 2009).





The mooring requirements for the chosen tidal turbine will depend on the style of turbine. Styles of mooring are presented in Figure 3-6.

A floating structure mounting (FSM) is usually on a floating platform or set of pontoons.

A near-surface structure mounting (NSM) is often a pier mounted structure.

A bottom structure mounting (BSM) is often in the style of a gravity base (weighted base) or a pile driven into the sea bed.



Figure 3-6: Mooring Styles (Kahn et al., 2009)

In general, vertical axis turbines have been designed to float at or near the surface to take advantage of the highest-speed currents, located approximately 1m below the surface (Karsten, McMillan, Lickley, & Haynes, 2008). This type of arrangement means mooring lines and anchors will need to be installed and the speed of the flow will directly affect the security of these lines.

In rivers, vertical and horizontal axis turbines have been placed near the surface in an overhang style or off a pier, which significantly reduces anchoring concerns and increases access for inspection and maintenance. If a barge or large floating turbine is planned as a semi-permanent structure, then anchor points need to be drilled in the bedrock to properly secure the turbine and/or barge (Wessner & Bear, 2009). A barge offers similar inspection and maintenance options as a pier, if the barge is designed appropriately.

Currently, most horizontal axis designs are being deployed on the sea bottom and are connected to a pile that is driven into the ocean floor or connected to a concrete surface that has been installed on the sea floor, known as a gravity base. The difficulties with this style of mooring include:

- the limited slack tide time available for easing pile or concrete platform installation,
- the cost of a drilling vessel,
- the time to install the turbine during slack tide,
- the availability and cost of a vessel capable of installing and lowering a very heavy (>1 ton) turbine,
- the accessibility of the turbine for inspection and maintenance, and
- the removal of turbine for maintenance.

Some of the clear benefits of the sea floor mounted turbines are:

- less interference with other marine activities,
- no line of sight concerns, and
- no shipping lane concerns.



Cafety: It is important to note that no business goal should take priority over the safety of employees or the public. A full risk identification, analysis, and mitigation should be undertaken on the system design and all operational activities. The marine environment is unforgiving and conditions can change in a very short period of time. Training and a high awareness of employee safety is absolutely necessary.

3.4 - INSTALLATION

A large component of both the capital cost and ongoing operation and maintenance costs is the deployment and recovery of the tidal turbine. The design of the system should be done with a goal to minimize these costs.

Safety: It is important to note that no business goal should take priority over the safety of employees or the public. A full risk identification, analysis, and mitigation should be undertaken on the system design and all operational activities. The marine environment is unforgiving and conditions can change in a very short period of time. Training and a high awareness of employee safety is absolutely necessary.

To a large degree, the type of tidal turbine defines the type of fixing (i.e. foundation or mooring) necessary, which narrows the types of installation techniques and processes. For example, if the tidal turbine is supported by a floating platform, the installation consists of fixing the mooring requirements, floating the platform with the tidal turbine installed to the site, and attaching the device to the mooring cables. If the system design calls for a pile-driven support into the ocean floor, then specialized drilling/piling barges will be required, along with extensive knowledge of the geology in the area. The pile(s) are installed over the course of a few weeks, after which the tidal turbine can be fixed to it/them. In the case of gravity bases, such as the Open Hydro demonstration turbine that was in the Minas Passage, the system is floated out to the site and then sunk to its intended position.

The types of fixing have different requirements. However, in respecting that marine operations are very costly, two common themes emerge:

• Carry out as much work as possible on shore, using appropriate lifting devices, welding machines, etc. and creating safe and predictable working conditions.

• Minimize the time on the water and build that consideration into the design of the system.

3.5 - MAINTENANCE

Tidal turbines and their associated systems will be designed for a finite operating time between overhauls and for an overall life. Corrosion and biofouling are very common aspects of machinery of any kind operating in a marine environment. With experience, the time to remedy deterioration caused by corrosion or biofouling can be predicted. Less predictable are unforeseen events such as foreign objects striking the turbine or extreme weather events causing problems.

If the tidal turbine is supported from a floating platform, it is possible to build into the design, equipment to lift the device from the water for inspection and routine maintenance. Other designs will require the tidal turbine be recovered and returned to an onshore or near-shore maintenance facility.



A system deployed on a gravity base is an example of a device that needs to be recovered and returned to shore. Very little maintenance can be done in the open ocean. Subsurface inspections may be possible with manned or unmanned submersibles, though the tidal currents limit their effectiveness. Diving in the vicinity of an operating turbine in tidal currents requires extremely high attention to detail to ensure the safety of personnel.

The tidal turbine technology providers will have developed recommended maintenance protocols, both routine and for overhauls. Those recommendations should be followed. Careful and complete records should be maintained, either manually or in an automated system. Photographs are extremely useful and each should carry a complete description, along with time stamp.

3.6 - POWER

3.6.1 - DEMAND AND GRID CONNECTION

When thinking about the challenges of integrating renewable energy into the power grid of Nova Scotia, it helps to understand how the grid works.



Figure 3-7: Frequency Range in hz (Freris & Infield, 2008)

Electrical transmission systems bring power across the province through power lines and are referred to as the "power grid." Distribution systems take power from the grid through substations and then distribute it to local customers.

The grid is a dynamic system that transmits power across the province; there is no power stored in the grid. This means the amount of power that is being made available through coal-fired plants, wind, hydro, and potentially, tidal, must be balanced with the amount of power being used by the population that is served (referred to as "load"). In electrical terms, the frequency of the power moving through the grid must stay within a restricted range (Figure



Figure 3-8: Ontario Demand Over 24 Hours

3-7, a graphic from the UK power network). In North America, this range is around 60hz. If the load on the grid is too high, the frequency will drop. If the power is too high, the frequency increases. The power transformers and elements of the electrical transmission systems are all designed to move power in a restricted frequency range; if the power moves out of that range, the transformers could become over-heated or damaged and the grid may fail.

Demand on the electrical system changes throughout the day, peaking in the evening when many people get home from school and work (Figure 3-8). The power that is generated must continually adjust through the day to meet the expected demand or load.



Idal power is produced according to the tide, so this means traditional power demand cannot be met solely by tidal power, unless storage is used. Options to address this issue include combining tidal power with other renewable energy sources (wind, solar), fill-in power systems, and changing the community power use pattern (e.g. have communities use dryers at night or only allow electric vehicle charging overnight).

47

Tidal power is produced according to the tide, so this means traditional power demand cannot be met solely by tidal power, unless storage is used. Options to address this issue include combining tidal power with other renewable energy sources (wind, solar), fill-in power systems, and changing the community power use pattern (e.g. have communities use dryers at night or only allow electric vehicle charging overnight).

NOVA SCOTIA IN CONTEXT: NOVA SCOTIA POWER INCORPORATED'S GENERATION INTERCONNECTION PROCEDURES

In Nova Scotia, the energy distribution system is managed by Nova Scotia Power Incorporated. To gain access to the distribution or transmission system and start selling energy, a standard set of interconnection studies and procedures must be followed. To read more, see Nova Scotia Power Incorporated's Generation Interconnection Procedures. http://oasis.nspower.ca/en/home/oasis/generationinterconnectionprocedures.aspx

3.6.2 - CABLES

Many tidal turbines require electrical power and often data interconnection to shore. The data cable is necessary to supply important performance information about the turbine in real time. Subsea cables are commonplace around the world; however, routing of these cables for the purposes of interconnecting islands, for example, is often designed to avoid high currents in order to ease installation and increase the survivability of the cable. For tidal turbines, high currents are necessary. There are specialized companies with experience in subsea cable installation (see Module 9: Opportunities and Strategies for Businesses for more detail on subsea cable inputs).

The design of the turbine will establish the magnitude of the voltage (volts) and current (amps) at the generator terminals. One way of visualizing current is to see it as the speed of water. Voltage can be seen as the height of water that is dropping to a lower level. Current and voltage have a relationship with respect to power: Power = Voltage x Current. Therefore, it can be seen that the higher the voltage, the lower the current (amps) for the same amount of power. The resistance of the wires transporting the power through the moving current causes some power to be lost in the form of heat. Copper has low resistance and is used for more efficient power transmission. When power is transported over a cable with high voltage and low current, there is less of an electrical power loss than when the current is high and the voltage is low. If the current is low, then there will be less copper needed, which reduces the overall cost of supply and installation. Because of this, there can be consideration for offshore power conditioning (which regulates voltage) and transformer equipment. Using conditioning, the voltage of the output from the turbine can be increased, the current decreased, and then smaller diameter cables (with less expensive copper) can be run to shore. However, more commonly, because of the expense to deploy and maintain electrical equipment in a marine environment, the voltage is usually maintained as generated and a larger diameter cable is used to accommodate the larger current.



The data cable can be included in the overall cable covering. The electrical insulation must be kept dry so the integrity of the covering and the electrical connectors is very high. If the covering and insulation fails, the system fails. In high current environments, an additional layering of armour is common. The cable is often installed in trenches, where possible. Trenching is a common practice to increase the survivability of the cable and keep it where it was placed. In some cases, naturally occurring trenches along the seabed can serve as a protective route for cables. The design can be either alternating current or direct current, as required by the generator.

3.6.3 - ONSHORE FACILITIES

Once the cable makes landfall, if it is being conveyed at generator terminal voltage, there should be power conditioning equipment, protection, control, and an electrical transformer as close as practical. Nova Scotia Power Incorporated will provide engineering assistance in designing these requirements. The developer is responsible for the provision of the equipment. This will reduce further losses by increasing the voltage to the level necessary for interconnection to the grid. The electric utility will provide interconnection requirements, which will allow the power conditioning equipment and protection and control to be designed and provided.

The data coming onshore can easily be accessed over standard telecommunications methods and monitoring can be done from anywhere. It is unlikely a dedicated onshore "operations center" is necessary.

For overhauls, a maintenance facility is required. Because of synergies between ship building and tidal energy, existing equipment at shipyards is likely adequate. Experienced tradespeople are also a significant asset found at existing shipyards and other marine-related industries, including offshore oil and gas. The equipment and infrastructure needed at maintenance facilities would include, but not be limited to:

- dry dock facilities;
- overhead cranes;
- laydown space for assembly, as well as welding machines; and
- metal forming tools and composite forming stations.



REFERENCES

Atlantis Strom (n.d.) Concept of an Economic Usage of Tidal Power http://www.atlantisstrom.de/description.html

Bates, C. (2008, July 17). Tidal power feeds electricity to National Grid in world first. The Daily Mail Online. Retrieved from http://www.dailymail.co.uk/sciencetech/article-1035978/Tidal-power-feeds-electricity-National-Grid-world-first.html.

Canadian Electricity Association. (2006). Power generation in Canada. Retrieved from www.electricity.ca

European Marine Energy Centre. <u>http://www.emec.org.uk</u>

- Freris, L., & Infield, D. (2008). Renewable energy in power systems. John Wiley & Sons Ltd. West Sussex, UK
- Hodge, B.K. (2010). Alternative energy systems and applications John Wiley & Sons Inc. US
- Kahn, M.J., Bhyuan, G., Iqbal, M.T., & Quaicoe, J.E. (2009). Hydrokinetic energy conversion systems and assessment of horizontal and vertical axis turbines for river and tidal applications: A technology status review. Applied Energy, 86, 1823-35
- Karsten, R. H., McMillan, J.M., Lickley, M.J., & Haynes, R.D. (2008). Assessment of tidal current energy in the Minas Passage, Bay of Fundy. Journal of Power and Energy, IMechE, 222, Part A, 493-507
- NERC, (2009) Balancing and frequency control: A Technical Document. Prepared by the NERC Resources Subcommittee Retrieved from <u>http://web.eecs.utk.edu/~tomsovic/ECE522/NERC%20Balancing%20and%20Frequency%20Control%20July%205%20</u> 2009.pdf
- Wessner, C., & Bear, C. (2009). Vertical axis hydrokinetic turbines: Practical and operating experience at Pointe du Bois, Manitoba. New Energy Corporation Inc., Calgary, Alberta, Canada. Retrieved from <u>http://www.newenergycorp.ca/LinkClick.aspx?filetic</u> <u>ket=7GLwd1%2BEqh4%3D&tabid=84&mid=471</u>