

To Examination on Optimum Utilisation of Kinetic Energy and Operational Features from Tidal Stream Turbine

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Abstract: Tidal stream energy represents a large resource along the power inflow of a current follows a cubic law and the tidal stream energy is only attractive where the current exceeds 2m/s during a sufficient time along the year. Some examples of the theoretical resource are shown for different sites and tide amplitude. The tidal stream velocity varies along the day and the month. The theoretical output is discussed for a typical site in terms of instantaneous power and annual production. For a given site and rotor diameter, economical factors invite to limit the electrical capacity to an economical optimum. The main features of the Marenergie type of tidal stream turbine are presented. The design has been governed by the following considerations: (a) This source of renewable energy must have an acceptable cost, so the overall concept must be economically viable (b) The tidal turbine must work in a submarine environment where maintenance is very difficult and the machinery must be made as simple as possible (c) All marine operations for installation and maintenance must take into account the strong currents prevailing in the potential sites (d) A compromise must be found between the capital cost and the yearly energy production and (e) The interaction of the waves with the current must be considered.

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1. Introduction

The kinetic energy of the currents can be harnessed by submarine tidal turbines. The physical phenomena involved must be investigated before designing the suitable equipment. The actual resource on a given site can be predicted if the local tidal streams are known, but the influence of the wave climate must also be considered.

The tidal stream resource

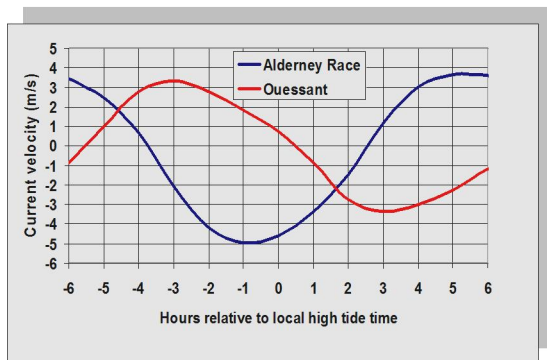
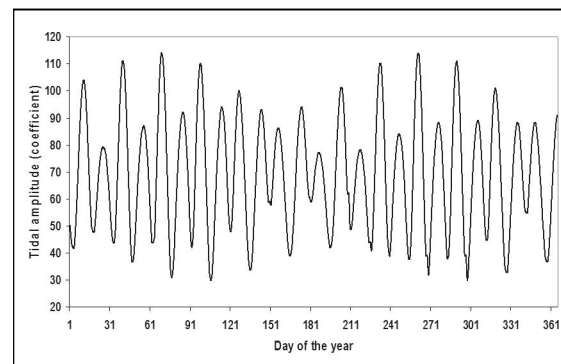


Figure 1: Typical current variation with time during a mean spring tide

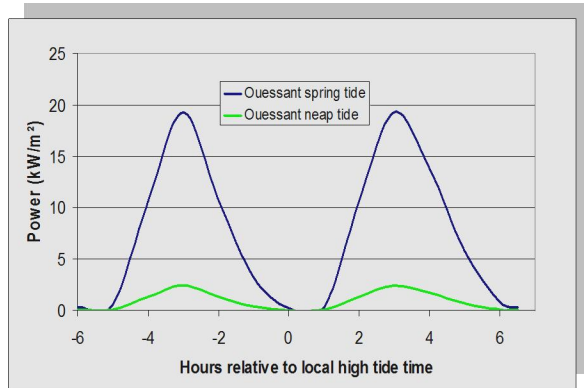
As a first approach, the power of the water stream through a tidal turbine rotor follows a cubic law similar to the power law of a wind turbine. This

equation shows that tidal stream energy is attractive where the tide creates strong currents. The suitable zones are found where the coast configuration restricts the tide propagation, around capes, between islands, in limited water depth areas. The water depth is limited to less than 50m. The overall theoretical resource is estimated at several gigawatts.



The tidal stream velocity varies along the day and the month. Figure 2 shows the value of the tide coefficient for Brest along the year 2001. The mean spring tide has a coefficient of 95, while the mean neap tide coefficient is 45. The power output is then variable along the time and varies from day to day.

Figure 3 shows the theoretical power input taking into account the equation [1]. The power inflow is notably stronger during spring tides than during neap tides.



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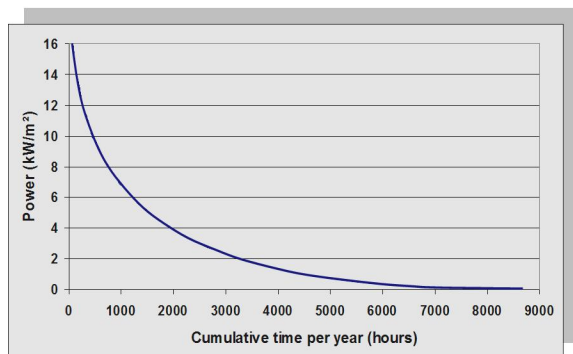


Figure 4: Cumulative distribution of the power inflow on a site with a maximum velocity of $3 \text{ m}\cdot\text{s}^{-1}$ during mean spring tide

The electrical generator of the turbine is characterized by its nominal power. The power input a rotor is able to exploit is then limited by the generator rating. When the current brings more power than this rating, the power is restricted to the nominal power and the excess of energy is lost. The theoretical resource is then a function of the turbine rating, as shown on figure 5. If high nominal power ratings are selected, the benefit on the energy production is marginal. Figures 4 and 5 represent the power inflow of the current. The actual electrical power must take into account the power coefficient of the turbine. Dividing the annual energy by the nominal power yields the equivalent number of hours of production. Figure 6 presents the values obtained, together with the number of hours at full load for the same example.

The investment cost of the turbine is a function of the power rating of the generator. Therefore, there is an optimum economical design which is considered to correspond to an equivalent production time of 2500

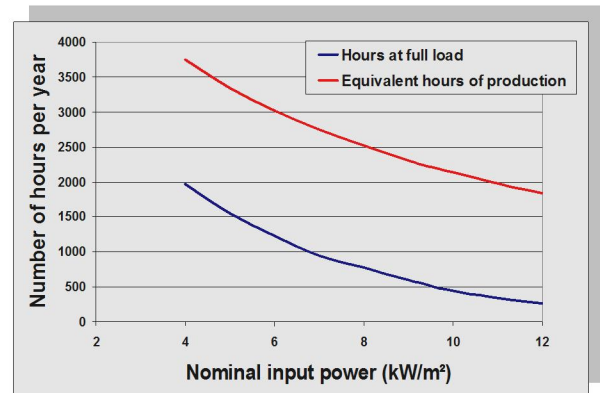
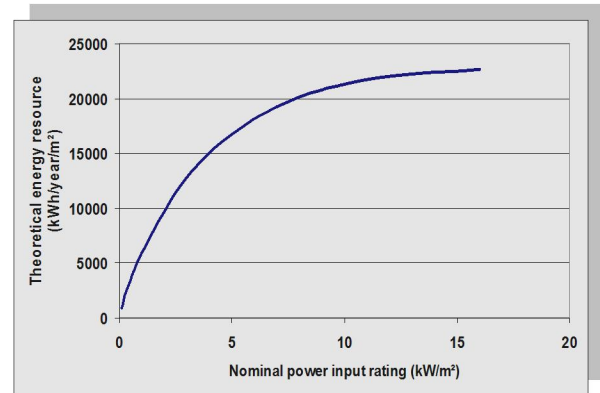


Figure 6: Relationship between the nominal power rating and the hours of production per year

2. Material and Methods

2.1 The Marenergie tidal turbine

When designing a tidal turbine, the following parameters must be taken into consideration: (a) The turbine must work in a submarine environment where maintenance is very difficult, so the machinery must be made as simple as possible (b) All marine operations for installation and maintenance must take into account the strong currents prevailing in the areas of interest (c) A compromise must be found between the capital cost and the yearly energy production and (d) The interaction of the waves with the current must be considered. The above mentioned facts led to the following solutions for the design of the turbine: (a) The rotor is maintained fixed in the space and the water flows alternatively in both directions during flood and ebb flows and (b) The number of moving

parts exposed to the sea water is kept to a minimum. The blades are fixed and welded onto the hub. The only moving part in sea water requiring some attention is the seal of the rotor shaft on the nacelle front face. The consequences of these choices are: (a) The rotor turns in both directions following the current direction and (b) The blades are symmetrical: Both ends are alternatively leading and trailing edges.

The peripheral velocity is kept at a relatively low level ($7\text{m}\cdot\text{s}^{-1}$) in order to avoid cavitations phenomena on the blades. The optimum velocity decreases when the number of blades is increased, and a correct velocity is obtained with 6 blades. The preliminary studies indicate the benefit of a circular belt at the rotor periphery. This enhances the blade efficiency and eliminates most of the potential vibrations. It should also limit the emission of low frequency noise at the blade tips. The actual design of the base depends on the soil nature. The rotor may be surrounded by a duct if required. Several turbines can be arranged in arrays as shown on figure 8. This increases the power collected locally and allows a better use of the submarine cable connecting the array to the grid onshore.

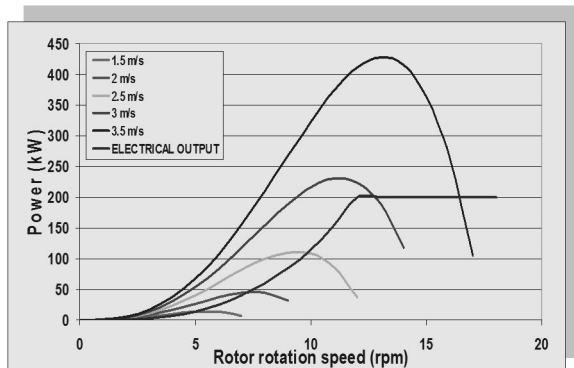
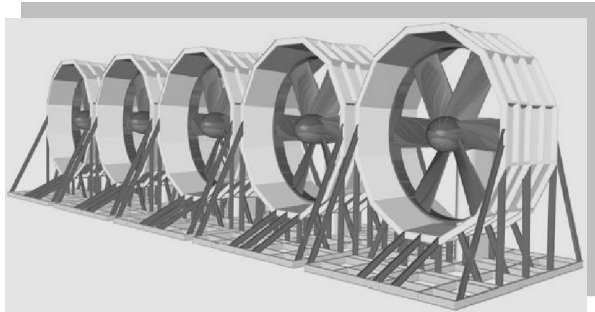


Figure 9: Typical characteristics of a Marenergie tidal turbine

A computer model of a rotor with symmetrical blades has been made. Figure 9 presents the power output of the rotor, as a function of the current

velocity and the rotation speed. For a given current there is an optimum rotation speed giving a power maximum. The figure also shows that the power is cancelled for a rotation speed called free wheeling speed, slightly higher than the optimum speed.

As discussed earlier, it is not advisable to use the maximum hydraulic power of the turbine when the current is particularly strong. The electrical generator is designed with a nominal power of 200 kW. When the current is sufficient, the power output is kept at this level. The rotor is then stabilized at a rotation speed corresponding to the equivalent hydraulic power. Figure 9 shows that this operation mode is stable. If for instance the rotor slows down for any reason, its hydraulic power increases and this causes the rotor to accelerate and return to the correct rotation speed.

The generator must be a variable speed type. It can be either an asynchronous machine with a wounded rotor fed by a separate variable frequency current or a synchronous machine with electromagnets or permanent magnets. Such generators are now extensively used in wind turbines.

3. Results

3.1 Wave current interaction

The water is put into movement not only by the tidal streams, but also by the wave action. The combination of both movements is a complex problem. In particular, it is known that a current flowing against the swell increases the wave height while the waves are attenuated when both phenomena are in the same direction. A discussion of the problem can be found in the literature and is subject to further research (2).

A regular swell traveling over an area of constant water depth is characterized by the height between crest and trough H and a period T . The distance between two successive crests is the wave length L which can be calculated by the following implicit relation:

$$L = \frac{gT^2}{2\pi} \tanh\left(2\pi \frac{d}{L}\right) \quad [2]$$

where g is the acceleration of gravity ($9.81 \text{ m}\cdot\text{s}^{-2}$) and d is the water depth in the absence of waves.

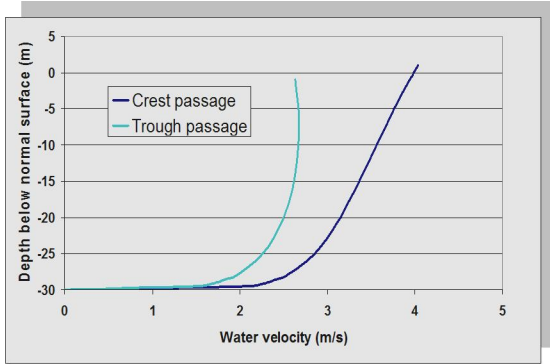
The amplitude of the wave movement decreases with the depth z below the surface. The horizontal velocity V_x induced by the wave action is given by the formula:

$$V_x = \frac{\pi H}{T} \cdot \frac{\text{Cosh}\left(\frac{2\pi(d-z)}{L}\right)}{\text{Cosh}\left(\frac{2\pi d}{L}\right)} \cdot \sin\left(2\pi\left(\frac{t}{T} - \frac{x}{L}\right)\right) \quad [3]$$

In the absence of wave, the current velocity is zero on the seabed and highest at the surface. The

velocity profile is generally approached by the following relationship between the elevation above the seabed and the local velocity:

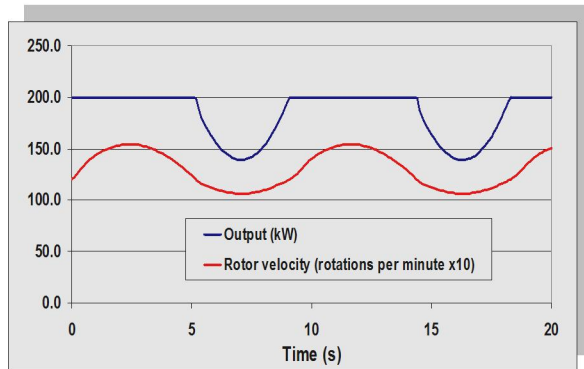
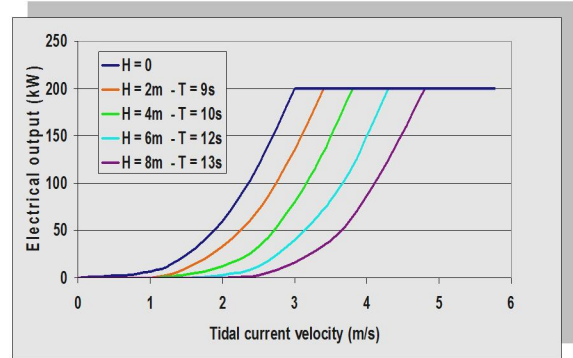
$$V_x = V_0 \cdot (d/z)^{1/7} \quad [4]$$



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fraction of the wave period. In order to obtain a constant output from a single turbine, the generator should be operated at a power level corresponding to the lowest power value during the wave period. The figure 12 shows the power calculated accordingly in the case of a regular swell, for different wave heights



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which would be constant and equal to the nominal value in the absence of waves decreases during a

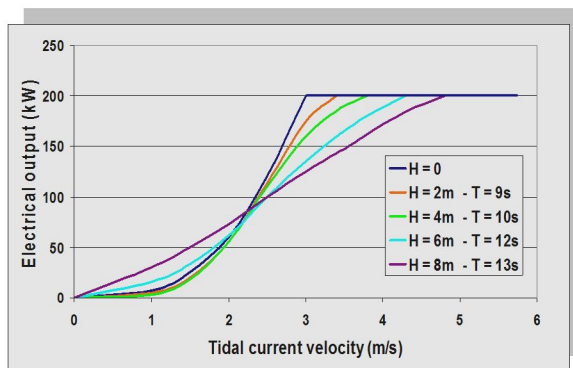


Figure 13: Average output of an array of turbines ideally spaced along the wave length

4. Conclusion

Tidal turbines can be optimized according to the local conditions prevailing on the different sites. The Marenergie tidal turbine is designed as simple as possible. Variable speed generators are required, similar to the types used in modern wind turbines. Waves may create power fluctuations and fatigue which must be taken into account in the sizing of the equipment. When assessing the potential energy productivity of a site, the local wave climate must be considered in addition to the tidal currents. The layout of the turbine arrays can be arranged in order to minimize the detrimental effect of the waves. The horizontal axis rotor is fixed in space. It is made of welded symmetrical blades which can accept the current from both sides. For a given current velocity, there is a rotation speed delivering the maximum power and a freewheeling rotation speed. The design of the electrical equipment and the operation philosophy takes this behavior into account. Waves interfere with the current and this causes power fluctuations. The wave action can severely limit the acceptable output of a single turbine, but the result is different for an array of many turbines.

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