Tidal Current Energy and the Sabella Turbine

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The tide along the European coast creates powerful currents which can be harnessed to produce electricity by underwater turbines. The machines must be designed to take into account the wave action and the worst environmental conditions in the open sea. SAIPEM participated in the design and the development of a new tidal turbine named Sabella. The turbine concept has been simplified as far as possible in order to limit the needs for maintenance. A first step of the development was the study, construction and test at sea of a 3m diameter demonstration unit.

1 Introduction

The tide along the European coast creates powerful currents. Their intensity can be well predicted, but vary along the time following the astronomical lunar and solar cycles. The evaluation of the peak kinetic energy exceeds 30GW. A part of this resource could be harnessed with tidal turbines installed at suitable locations. The request to increase the share of renewable energies raised the interest for the development of tidal current energy. Some French companies decided to join efforts to develop a tidal turbine specially suited for the local conditions (1,2).

A first unit was designed in order to demonstrate the validity of the turbine concept. The demonstration project was named Sabella.

2 The energy resource

Figure 1 shows the map of the maximum current velocities in the English Channel. The maximum current velocity during spring tides is typically 2 to 3 m/s, although stronger current exist on a few zones, like the Alderney Race.
On these sites, the water depth remains relatively shallow, limited to less than 50 m in most cases.

Figure 1 Map of the tidal currents in the English Channel. Maximum velocity during a mean spring tide

Because of the shallow depth, the most severe waves are limited to less than about 13 m. Storms must however be taken into account for the design, as they are responsible for the extreme mechanical loads.

The interesting sites are located around capes or islands, where the tidal flow is restricted by the topography. The coast is never far away, so that the cable length to shore is only a few kilometers. On the other hand these areas are heavily frequented by surface vessels. They are also places of high biological interest, a fact to be carefully considered in every project.

Table 1 Typical characteristics of potential sites

<table>
<thead>
<tr>
<th>Nominal current velocity</th>
<th>2 to 3 m/s (4 to 6 knots)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water depth</td>
<td>20 m – 50 m</td>
</tr>
<tr>
<td>Storm waves</td>
<td>Hmax = 13 m – Tp = 11 s</td>
</tr>
<tr>
<td>Soil conditions</td>
<td>Gravel – consolidated sand – rock</td>
</tr>
<tr>
<td>Tidal range</td>
<td>5 m – 11 m</td>
</tr>
<tr>
<td>Distance to land</td>
<td>Typical 3 km – 10 km</td>
</tr>
</tbody>
</table>
3 Theoretical design of tidal turbines

The kinetic energy resource of a current flowing with a velocity \( V \) is given by the equation [1]:

\[ W = \frac{\pi}{8} \cdot \rho \cdot C_p \cdot D^2 \cdot V^3 \]

Where \( \rho \) is the water density (1024 kg/m\(^3\)) – \( C_p \) the turbine efficiency – \( D \) the rotor diameter - \( V \) the water velocity.

This equation shows that the current velocity and the rotor diameter are more important parameters than the rotor efficiency. Table 2 compares the rotor diameters of turbines required to obtain 200 kW following the nominal current velocity. It can be seen that the turbine is relatively small in high speed currents, but have to be unacceptably large where the current is slow. Keeping in mind that a 200 kW wind turbine has a rotor diameter of 25 m, it is obvious that tidal turbines are not attractive if the current does not exceed 2 m/s.

<table>
<thead>
<tr>
<th>Current velocity</th>
<th>1 m/s</th>
<th>2 m/s</th>
<th>3 m/s</th>
<th>4 m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotor diameter</td>
<td>37.7 m</td>
<td>13.3 m</td>
<td>7.3 m</td>
<td>4.7 m</td>
</tr>
</tbody>
</table>

The water velocity varies with the depth, being maximal at the surface and zero at the bottom. The most widely accepted relationship is:

\[ V_z = V_s \cdot (z/d)^{1/7} \]

Where \( V_s \) is the surface velocity, \( d \) the water depth, \( z \) the altitude above the sea bottom.

Moreover, the open sea is agitated by waves. In the shallow areas considered, the wave action can be felt down to the sea floor, in particular during storm events when long period waves are observed.
Figure 2 Velocity profile with waves following current - Waves : $H_s = 2 \text{ m} - T_p = 9 \text{ s}$

Figure 2 makes it clear that rotor blades undergo cyclic efforts at each revolution. This must be taken into account in the design in order to avoid a premature fatigue.

4 Design of the Sabella turbine

The machines are working completely immersed in a hostile environment. It is therefore a prime concern to minimize the risk of failure and the need for maintenance. In order to fulfill this objective, the turbine is designed as a simple heavy duty equipment:

- The energy capture device is a horizontal axis rotor
- The rotation sense is reversed with the current and the rotor has symmetrical blades
- The rotation speed varies with the current velocity
- The turbines are installed at or below water mid-depth, away from the most severe wave action zone
- The rotor has fixed blades solidly attached to the shaft. The blades have no pitch adjusting system
- The blade tips are linked by a circular ring which restricts oscillations in the rotor plane and out of the rotor plane directions

The hydrodynamic forces on the structure should be minimized, because an oversize increases the cost. The overall volume of the structure and the size of
the members are reduced as far as possible. This has a twofold benefit on the cost, because less material is utilized and lower efforts have to be resisted. In addition, a lighter structure requires a more economical installation barge.

The number and the shape of the blades are selected thanks to a hydrodynamic calculation model. The blade section is an ellipse with a thickness equal to 15% of the cord. In order to avoid the onset of cavitation, the tip speed velocity is limited to less than 10 m/s. The final design incorporates 6 blades.

The model makes it possible to draw the theoretical power characteristics of the turbine. A typical example is shown on Figure 3 for a rotor with a diameter of 10 m.

![Figure 3](image)

**Figure 3** Typical relationship between water velocity, rotation speed and rotor power

The current speed has a very important influence on the power, as could be expected from the equation [1]. For a given water velocity there is an optimum rotation speed. Beyond the maximum, the power curve drops to zero for a rotation speed which corresponds to the free running condition, when no power is extracted by the generator.

The foundation design must be selected according to the soil characteristics. There is no one-fits-all solution. On most sites where strong current are observed, the soil is often composed of hard sand and gravel, although moving sand dunes are reported. In the following, a gravity base structure is considered, but it should not be concluded this choice is inherent to the technology. Other types of foundations will be adopted in the future if this is required by the local soil conditions.
The structure includes 2 parts:

- a base which rests on the seafloor
- the turbine itself (rotor and nacelle) attached to a support frame

The base is held on the bottom by appropriate weights (gravity base). 2 vertical tubes guide the turbine during the handling operations. The special shapes of the 2 parts of the structure match together, allowing an easy installation.

Figure 4 Installation sequence of a Sabella tidal turbine

No divers are needed. The barge crane is equipped with cameras and attitude control propellers which make it possible for the operator on board of the vessel to control the operations. In turbid waters, acoustic devices can also be used to facilitate the approach.

Maintenance is greatly simplified and can be performed even when the current is not zero. Indeed, the current can be exploited to help the operations.
5 The Sabella demonstration project

Following the R&D phase described in the above, the consortium felt the need to test the concept at sea.

Budgetary reasons led to the decision to make first a demonstration unit. It would incorporate all the basic elements of the tidal turbine, but the dimensions would be scaled down in order to limit the expenses.

The local authorities showed a strong interest for the idea and offered to support the Sabella Project.

For administrative reasons, the turbine is not fitted with a power cable to land. The energy produced is consumed by resistors installed on the machine.

The objectives of the project can be summarized as follows:

- Test of the overall concept (fixed bidirectional rotor, support structure, installation and handling procedure)
- Survey the influence of the turbine on the soil stability
- Observe the behavior of the fauna around the unit
- Measure the noise emission
- Evaluate the acceptance from the other users of the sea and of the public
- Discover what only tests at sea can teach

The demonstration unit has the following characteristics:

- Rotor diameter is 3 meters
- The blades are in glass fiber reinforced plastic with a steel skeleton

The generator is a direct drive permanent magnets oil filled alternator. Its nominal power is 10kW although it was not expected to obtain the full power on this site.

- The structure is made of mild steel.
- Corrosion protection is provided by coating and sacrificial zinc anodes
Figure 5  View of the Sabella turbine

The lessons learnt during the project can be summarized as follows:

- The concept allows the easy installation and removal.

- The vessels were not fitted with dynamic positioning system. It was made clear that it is possible to utilize the current. The vessel is anchored ahead of the final location and allowed to drift slightly until the right position is obtained. Dynamic positioning is therefore not absolutely required, although it will be considered in the industrial phase to reduce the time required for the operations and decrease the maintenance costs when many turbines will have to be serviced.

- The rotation speed and the power delivery are in good agreement with the predicted values. Accurate comparison was hindered by the difficulty to assess precisely the instantaneous water velocity.

The noise was measured during a spring tide period. The noise generated by the turbine could hardly be detected among the background level.
Figure 6  Fish school around the Sabella turbine

The turbine was regularly inspected by divers. Fish schools were systematically observed near the installation.

The rotor which is painted with an anti-fouling coating remained clean during the whole period. On the static parts which were not protected against fouling, the marine growth is noticeable and representative of the local marine life. The fouling is not regarded as a problem so far.

6  Next development phase

The further development of the technology includes the construction and test at sea of a 10 m diameter unit. The 200 kW turbine will be connected to the on-shore grid, in order to complete the engineering and the testing of the electrical part of the tidal turbine.

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