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EXPLOITATION OF TIDAL ENERGY IN GUINEA-BISSAU

Executive Summary.

Foreword.

The present proposal originates from some preliminary contacts established between the Department of Civil, Environmental and Architectural Engineering (DICAT) of the University of Genoa (Italy) and the ONLUS Programma Sviluppo 76 (PS76) which operates in Guinea-Bissau, in cooperation with the local ONG “Amigos da Guiné-Bissau”. These contacts were motivated by the aim to investigate the possibility to produce electric energy in Guinea-Bissau exploiting the potential energy associated with tides. Previous successful cooperations had already been established between the same PS76 and the faculty of Architecture in the field of tourism and between DICAT and PS76 on a project concerning the problem of energy production using palm oil.

1. Exploiting tidal energy

Energy from tides is one of the best available renewable sources. In contrast to other clean sources, such as wind, solar, geothermal etc., tides can be predicted for centuries into the future; thus power outputs can be accurately calculated far in advance, allowing for easy integration with existing power networks. However, tidal energy is distributed over large areas, which makes its exploitation more difficult. Moreover, tidal power systems do not generate electricity at a steady rate, hence they are generally unable to meet peak demand.

There are basically two ways of generating electricity from tides: by building a *tidal barrage* across an estuary or a bay experiencing high tidal range, or by extracting energy directly from *tidal currents*.

i) In the former case, a barrage is built across an estuary or a bay that experiences an adequate tidal range. The purpose is to create a basin where water level raises and falls with a time law different from that of the open sea, in order to create a hydrostatic head. The turbines placed along the barrage generate power as water flows in and out the bay. The system is then similar to a low head hydro dam. The construction of a barrage requires considerable civil engineering works and has an environmental impact, not only during dam construction. The yearly energy reserve E [KWh/year] associated with a plant of this type is readily estimated and reads:

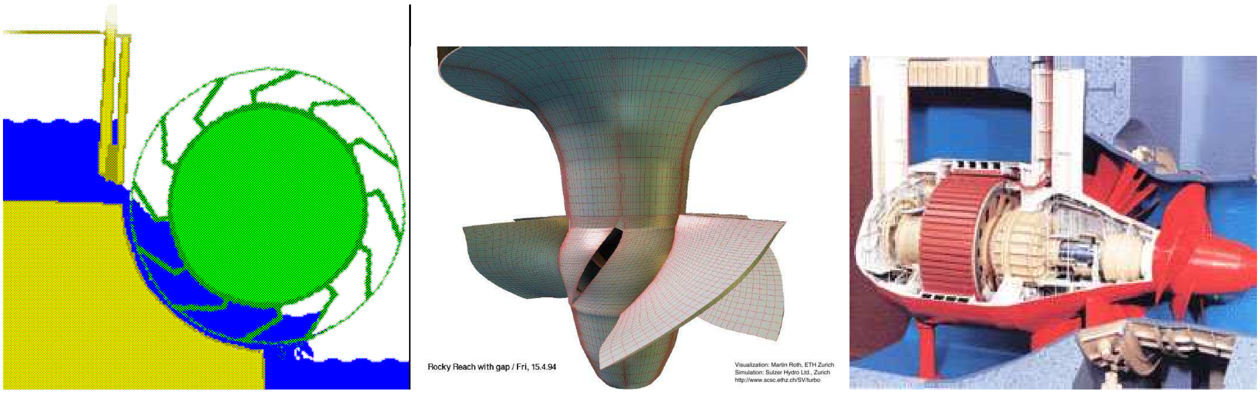
$$E = 1.97\, S\, R^2$$

with S [m^2] the area of the basin surface and R [m] the tidal range: hence, **roughly 2 GWh per square Km of basin area for a one meter tidal range**. The quadratic dependence of the latter relationship on tidal range suggests the importance of choosing suitable sites for these plants.

There are different types of turbines that can be used for energy production in a tidal barrage system:

- *waterwheels*, suitable for use in a developing country because of their simple construction and working conditions;
- *Kaplan* turbines, widely used in low head power production;
- *Bulb* turbines, which are usually installed in barrage tidal plants.

ii) The second technology extracts energy from free flowing tidal currents, which implies much less civil engineering work and less environmental impact at the site. A great deal of attention was first focused on this source of energy during the oil crisis in the 1970s. However, only recently, developments in power electronics, in the offshore industry and in wind power technology have brought tidal energy much closer to an introduction in the electricity market. At present, there are a number of promising and more or less innovative concepts for Marine Current Energy Converters.



a) b) c)

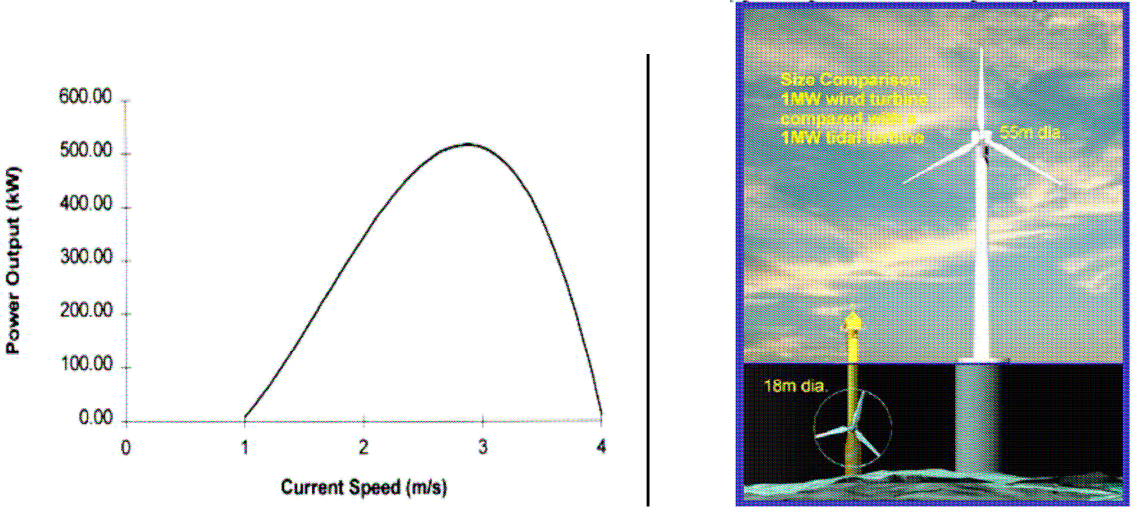
Fig.1 Different types of turbines for tidal applications: a) Breast-shot waterwheel; b) Kaplan turbine (Martin Roth, ETH Zurich); c) Bulb turbine (Hitachi, Ltd. 1994, 2005).

The power that can be converted to a useable mechanical form by a free flow turbine is:

$$P(t) = \frac{1}{2}\rho A_0 U(t)^3 \eta$$

where η is an *efficiency coefficient*, A_0 [m^2] is the frontal area of the turbine, U [m/s] is the undisturbed speed of the tidal current and ρ [kg/m^3] is the water density. Hence, **the available power is 0.175 KW for a 1 m^2 frontal area and a 1 m/s flow speed**. Increasing the diameter by a factor 3 and doubling the flow speed, the available power increases by two orders of magnitude; a current speed of 5 m/s would even allow to amplify power by three orders of magnitude!! Note that the cubic dependence of power on current speed makes wind turbines more productive; however, the linear dependence on fluid density favours tidal turbines.

The value of η for a turbine in a flow of an incompressible fluid is limited to a maximum theoretical value around 35% (Gorban et al., 2001). The value of η for a real device is generally a function of the ratio between the speed of the turbine tip and the flow speed, which is commonly known as the *tip speed ratio*. Most suggested designs for tidal turbines operate at a constant rotational speed. This allows for a relationship between the flow speed and the power output to be determined (Fig. 2).



a) b)

Fig. 2: a) Power output curve assuming a 10-s rotational period, based upon the η- λ curve (Bryden et al., 1997) b) Size comparison of a 1 MW wind and tidal turbine (Marine Current Turbines Ltd.).

For decades scientists and engineers have unsuccessfully tried to utilize conventional turbines for free and low-head hydro: hydraulic turbines which prove very efficient under high heads become very expensive in applications for low and ultra low-head hydroelectric stations. Two types of turbines have been proposed in recent times to overcome the latter problems:

- horizontal axis turbines (axial flow turbine, see fig. 3)
- vertical axis turbines (cross flow turbine, fig. 3 and fig. 4)

Suitable designs have led to considerable improvement of the efficiency of these turbines, which may reach values as high as 35 %.

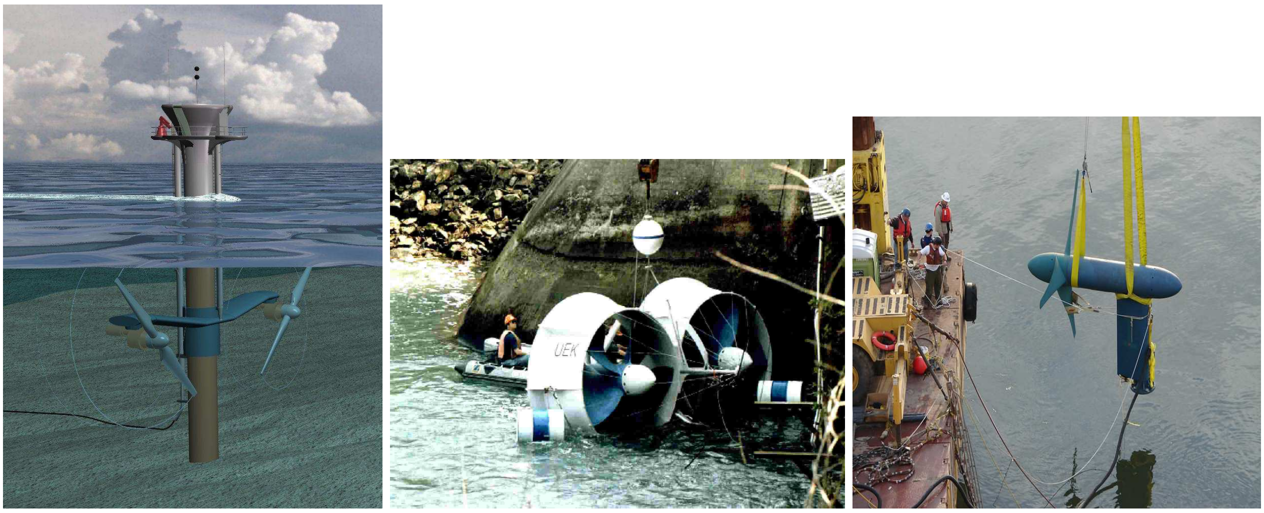

a) b) c)

Fig. 3: a) Artist's impression of MCT Seagen pile-mounted twin rotor tidal turbine (Marine Current Turbines Ltd). b) UEK Twin Turbines prepared for demonstration (Underwater Electric Kite). c) Verdant Power Free-flow Turbine Being Deployed in East River (December 2006).

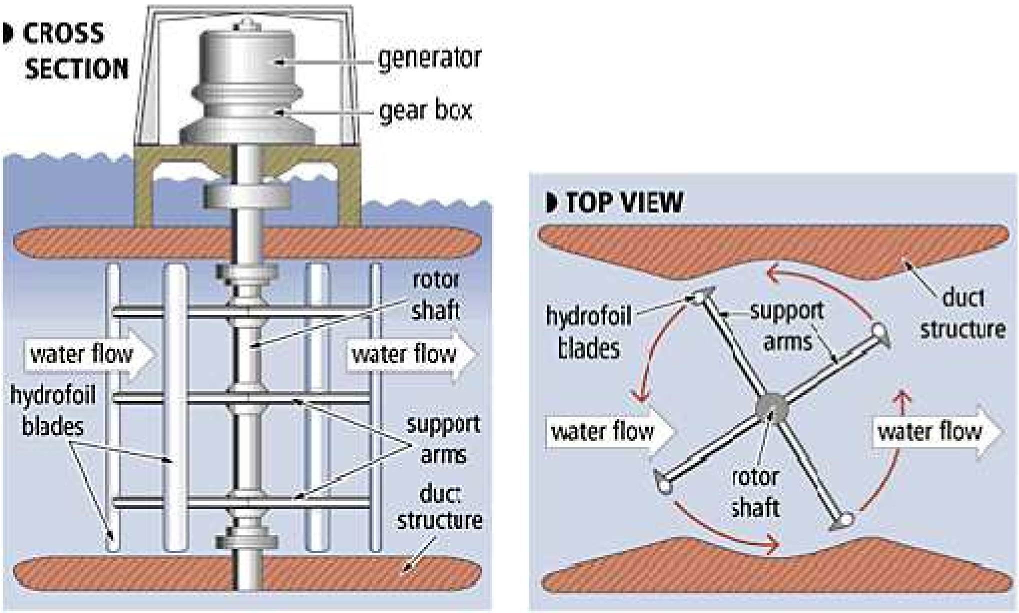


Fig.4: Davis Hydro vertical-axis turbine (Blue Energy International).

2. Why Guinea-Bissau ?

Located on the West African coast (fig. 5), Guinea-Bissau is a small country, one of the poorest countries in the world.

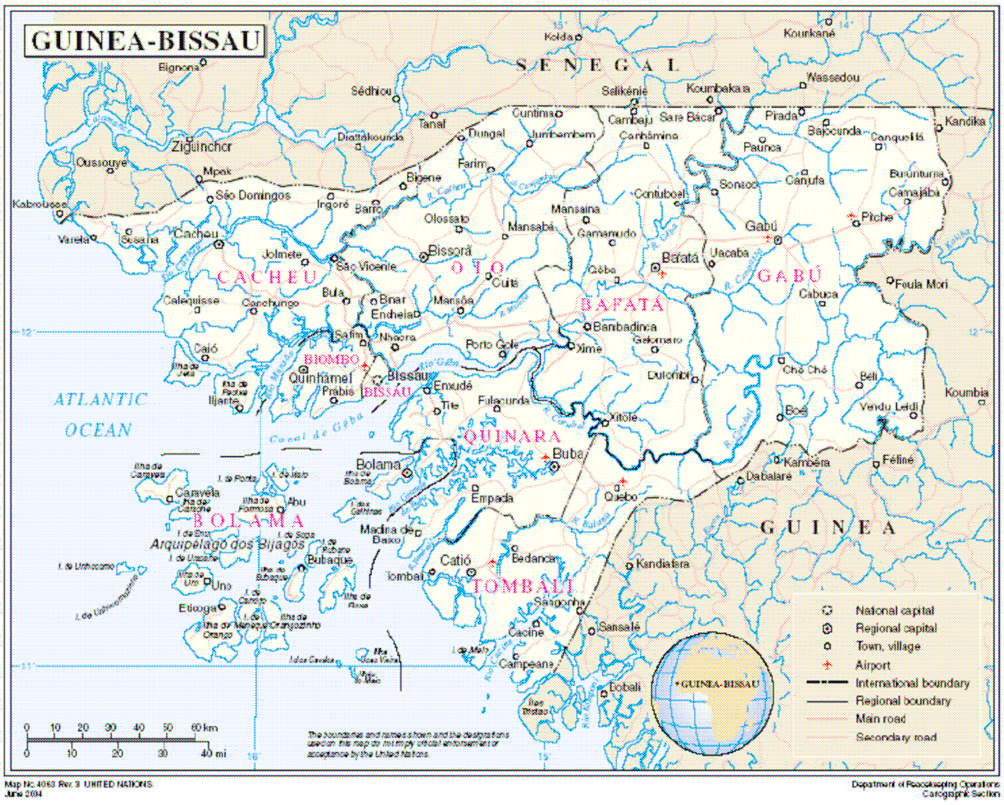


Fig. 5: Map of Guinea-Bissau (Flash Appeal, 2006).

Guinea-Bissau has one of the *lowest electrification rates and highest electric service cost in Africa*. The country is completely dependent on petroleum products, despite its own high energy potential, especially in terms of hydroelectric power. Peak demand for electricity is estimated at 15 MW but the available units have the capacity to produce 11.8 MW, about 2/3 of total demand.
The inefficiency of the power sector has disrupted economic activity to the point that many business activities are forced to secure their own generating capacity at high economic cost. The inefficiency of the power sector has also had a direct negative impact on the water sector: the irregularity of water supply in Bissau is largely due to frequent power cuts which disrupt regular water pumping. Importing electric power produced in neighbouring countries into Guinea Bissau (e.g. from power plants built on the Gambia river (in Gambia) and Konkouré in Guinea Conakry) is currently under discussion as are studies for the Saltinho dam on the Corubal river (power of 20 MW for an average production of 150 GWh/year).

A major natural resource of Guinea-Bissau is the high value of *tidal range* experienced on its coast, the *highest* along the west African coast. Moreover, the presence of tidal estuaries further enhances the tidal range: its maximum recorded value is 6.80 m in Porto Gole, on the banks of Rio Geba. The tidal stations located along the coasts of the country are shown in the image below (fig. 6).

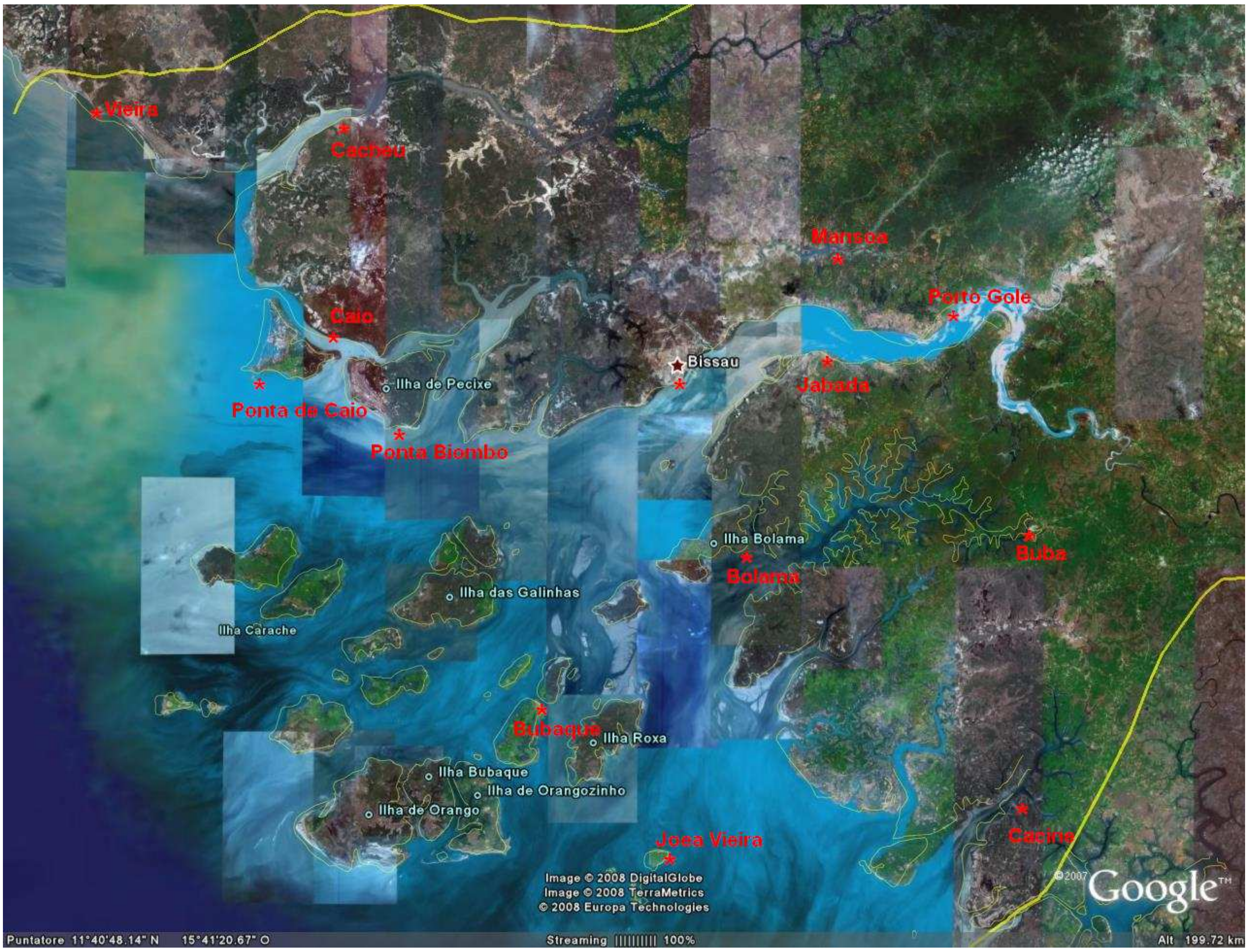


Fig. 6: Satellite image of Guinea-Bissau with specified in red the tidal stations (©Google 2007).

In the following table (table 1) typical values of maximum and minimum tidal amplitude are listed.

		Max Amplitude [m]	Min Amplitude [m]
Rio Mansoa	Caio	1.25	0.8
Rio Geba	Bissau	2.5	1.25
	Jabada	2.85	1.6
	Porto Gole	3.4	1.9
Islands	Bubaque	2	1.1

Table 1: Values of maximum and minimum tidal amplitudes in various sites of Guinea-Bissau.

3. Feasible sites for barrage plants production.

The first investigated site is a small basin on the side of Rio Mansoa, shown in the figure 7. The site is located about 100 km inland from the estuary mouth and only 2 km away from the village of Fanhé, where PS76 is realizing other projects of cooperation. The local values of the tidal amplitude were estimated by a 1-D numerical model of tide propagation, while the length of the barrage and the basin surface area were estimated by satellite images. The average channel depth in the section of the barrage was estimated assuming a linear bottom profile along the estuary.

For this site, with an annual average tidal amplitude of 2.2 m, a basin surface area of 29000 m^2

and a barrage length of 72 m, an average diurnal power potential of 126 KW can be estimated: assuming a 34 % efficiency, the average power output may reach 43 KW.

Fig. 7: Satellite image of the site near Fanhé where a small-size tidal power plant could be located (©Google 2007).

Next, we have considered the possibility of installing a larger tidal plant near Bissau, using a minor tributary of the Rio Geba, shown below (figure 8), as a basin. The barrage was located at a distance of about 1 km from the capital Bissau, where the estuary width is smaller, in order to reduce the barrage length and decrease its cost. The importance of the site is its proximity to the capital: the power produced could then supply the city electric network.
For this site, with an annual average tidal amplitude of 1.9 m, a basin surface area of 1.12 Km^2 and a barrage length of 154 m, we have estimated an average power of about 1 MW.

Fig. 8: Satellite image of the site near Bissau where a medium-size tidal power plant could be located (©Google 2007).

Finally, we have considered the possibility of installing a large tidal plant near Porto Gole, the

location where the recorded tidal range is highest. As shown in the figure 9, the barrage is located in a fairly narrow section, in order to reduce its length and its cost. The role of the basin is played by the wide landward reach of Rio Geba.
For this site, with an annual average tidal amplitude of 3.4 m, a basin surface area of 22.5 Km^2 and a barrage length of 2 Km, we have estimated an average power of about 50 MW.

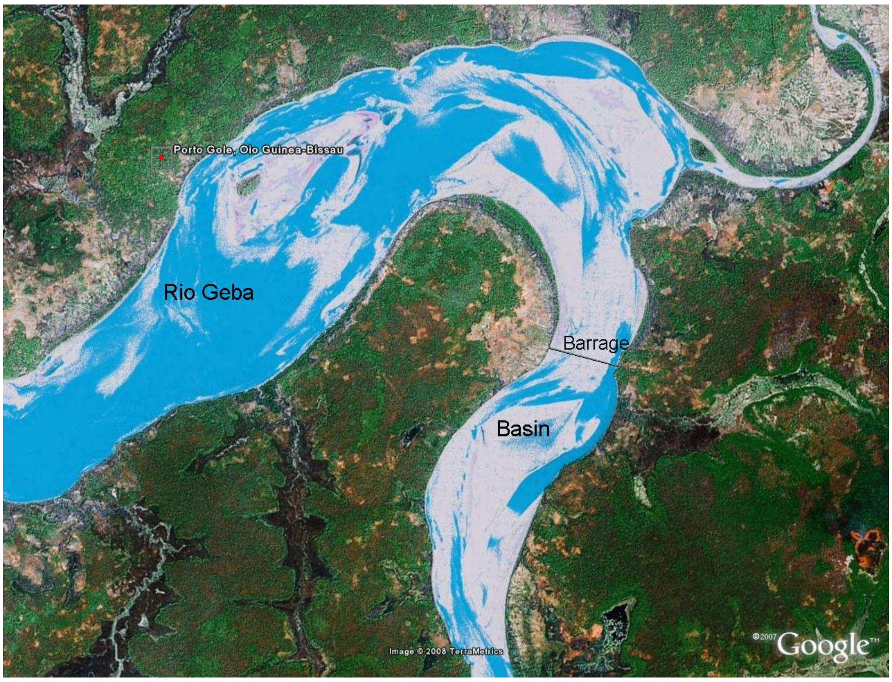


Fig. 9: Satellite image of the site near Porto Gole where a large-size tidal power plant could be located(©Google 2007).

4. Feasible sites for small scale production (free flow turbines).

We then investigated the possibility of exploiting the power of tidal currents directly, installing one (or an array of) “*free-flow*” turbine. We chose a Darrieus type turbine with 3 m diameter, as this is one of the few prototypes suitable to low speed environments, already available in the market. Various sites were investigated:

- along the Rio Geba each turbine would allow production of 0.67 KW close to the capital Bissau and 0.71 KW at Porto Gole, upstream a natural narrowing of the stream;
- along the Rio Mansoa the flow speed does not attain high values (allowing at most 0.37 KW power production close to Fanhé), which suggests the inadequacy of the site for the installation of a free-flow turbine;
- close to Bubaque, in a natural strait between two adjacent islands belonging to the Dos Bijagos Arquipelago, rather high values of current speed have been measured; in this case a power as high as 1.26 KW could be produced by a single turbine: this production could be exploited by small hotels located nearby.

Note that, though the **power output per turbine is fairly small**, however it has several important features: it is durable, predictable and without any environmental and visual impact. Needless to say, the power output can be readily increased by installing an **array of turbines**: in this respect, it should be noted that the cross section of Rio Geba close to Bissau (11 km in width and 8 m in average depth) is such that the maximum kinetic power of the flow reaches a value as high as 50 MW.

A systematic **field campaign** will have to be performed in order to make progress with the present feasibility study.

5. A novel solution to enhance small scale productivity.

We have finally investigated the possibility to extract tidal power from natural or suitably designed artificial inlets connecting a body of water subject to tidal oscillations to a basin. In fact, knowing inlet geometry, size of the basin and characteristics of the forcing tidal oscillation, one can readily determine the inlet hydrodynamics. It turns out that conditions exist which let the tide ‘resonate’ in the inlet: under these conditions, which can be artificially set, power production would be at its optimum.

In particular, fairly typical conditions would be: a tidal amplitude (near Bissau) a_0 = 1.9 m; a basin surface area S = 150,000 m^2; an inlet length L_i = 10 m; an inlet depth Y_0 = 5 m; an inlet width B = 4 m. The cross section of the inlet is then narrow enough to obtain high speed values, but wide enough to install a Gorlov turbine (Fig. 10), 1 m in height and 2.5 m in width.

Fig. 10: Double and triple helical Gorlov turbine (Lucid energy technologies).

The estimated average **power output per turbine**, under the latter conditions ranges about **4 KW four times larger** than those predicted for free flow turbines examined above. The latter value would **increase to 8.4 KW for a tidal amplitude of 2.5 m**.

6. Preliminary cost estimates and conclusions.

Preliminary cost estimates suggest that, since the present cost of 1 KWh produced by a diesel generator in Guinea-Bissau ranges about 0.38 € (neglecting the cost of the generator, its installation and maintenance), the **tidal installations** discussed **would pay for themselves in a period of roughly 10 years**. The feasibility of the above solutions is bound to increase with the rapid acceleration of the price of oil and with the foreseeable improvements of tidal plant technology.

Appropriate developments of the present study will also be needed in order to define the best tools to associate an **energy storage** system to overcome the problem of the fluctuating character of the tidal power. This issue may have several solutions, including that of employing an additional power source.

References

Gorban A. N., Gorlov A. M. and Silantyev V. M.. Limits of the Turbine Efficiency for Free Fluid Flow, *ASME Journal of Energy Resources Technology*,123 ,311-317. 2001