Tidal Power for San Francisco

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***Abstract*- The City of San Francisco is uniquely situated to take advantage of a tremendous tidal resource in its backyard. City Officials recently passed a resolution committing the City to developing a 1 MW tidal power station within the next three years. Several choice sites are available within the San Francisco Bay. Models of bay circulation developed with 20-years of recorded data exist to verify the tidal resource. A new technology with no moving parts underwater, takes advantage of a venturi created by design of the subsea tidal station. All mechanical moving parts for the system are on land including conventional air-driven turbines used to generate electricity from the venturi suction. An assessment of environmental considerations for using this technology are briefly discussed.**

I. INTRODUCTION

The City of San Francisco is evaluating the feasibility of installing a system in the Golden Gate to harness the tidally driven currents. Several factors have lead to and support the recent political decision to promote and endorse tidal power in San Francisco including:

- realization that hydrocarbons are a finite and limited source of energy that will not support long-term sustainable energy needs,
- human health and ecological threat of combusted hydrocarbons including atmospheric emission of greenhouse gases and other pollutants,
- local economies need to develop self-sufficient regional energy solutions to support and sustain local jobs and economic development,
- San Francisco's unique geographical setting with access to tremendous tidal resource,
- extremely reliable and predictable nature of tidal resources independent of local weather conditions,
- prudent energy management dictates expanding the portfolio of renewable energy generation projects, and
- tidal power can provide municipal power needs without contributing carbon dioxide to the atmosphere as the City is committed to reducing greenhouse gas emission to 20% of 1990 levels by 2012.

The citizens (more correctly, the voters) of San Francisco overwhelming support the implementation of renewable energy for electrical power generation as evidence by passing of recent bond measures (see for example www.voteSolar.org). Their Board of Supervisors recently (May 6, 2003) unanimously passed a resolution to develop a 1 MW tidal power project within three years.

Our observations address three topics: the available resource in San Francisco Bay, a specific tidal energy technology that takes advantage of a Venturi tube, and environmental considerations related to this technology. A Venturi tube is simply a tube that is narrower in the middle than at the ends. When fluid passes through the restriction, the narrowing (constriction) causes the fluid to accelerate through the middle of the tube according to the Bernoulli principle. In the following discussion, we will focus on a pilot plant built with this technology with a capacity of 1 MW.

II. RESOURCE

Tidal energy works by capturing kinetic energy from the gravitation attraction of the Earth- Moon-Sun system in very long wavelength perturbations in the ocean, resulting in kinetic energy both in the deep oceans (oceanic currents) and offshore (tides and currents). The mechanical component of tidal energy has a global resource base of approximately 30 Tera Watt (TW) (see Table 1).

TABLE 1.
GLOBAL RENEWABLE RESOURCES

Resource	Potential Energy (TW)
Solar	90,000
Wind	1200
Tidal	30
Wave	3

Note: Tera Watt is 10^9 Watts.
Source: [1]

The tides in San Francisco Bay are mixed semi-diurnal tides, denoting two unequal high tides and two unequal low tides daily. Tidal resource is abundant in San Francisco's Golden Gate passage and at other locations within the bay. The maximum tidal heights during spring tide are on the order of 2 m. It is estimated that upwards of 2.5 billion m^3 pass through the Golden Gate narrows at flow rates up to 4 knots (~2 m/s) every 6 hours. The San Francisco bay area's tidal resource could exceed 2500 MW.

Tides can generate some power for up 17 hours per day. The generation periods coincide with "peak" energy demand about 78% of the time annually. Within a small (2%) margin of error, tidal patterns allow for excellent long-term power predictions to establish a reliable power base for integration into existing grid.

Tidal energy potential can be estimated with existing models, such as UnTRIM model (R. Chang, USGS, Menlo Park, pers. comm.). The TRIM model (Tidal, Residual, Intertidal Mudflat) was initially developed as a response to an oil spill in S.F. Bay in January 1971 [2]. A marine nowcast system used for navigational safety [3] is an

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extension of the oil spill efforts into an unstructured grid (UnTRIM). The San Francisco Physical Oceanography Real-Time System (www.sfports.wr.usgs.gov) couples over 20 years of USGS tidal data with a 3-D computational model [4] to provide real-time information from deployed instruments in SF Bay. The UnTRIM model will allow for precise assessment of the tidal resource at specific locations. Numerical modeling, especially if the model is developed and well-calibrated is a very cost effective

III. TECHNOLOGY

Systems to extract energy from tidal power have been around since at least 900 A.D. [5]. Modern commercial-scale systems have focused on utilizing a barrage or low dam across an estuary or inlet to impound rising tides and generate electricity with low-head turbines on the tides retreat. In the last decade, developers of tidal power have shifted their focus from estuarine barrage systems, which were successful in the past, to tapping coastal water currents induced by the ebb and flow of tides [6]. Part of this paradigm shift is the realization that barrier-type tidal power systems are most economical for plants with a capacity of several thousand megawatts. However, the potential locations of these facilities is very selective and environmentally disruptive requiring a commitment of several years and large sums of money to develop without any assurance that the projects will be completed. While most developers have focused on horizontal or vertical turbines, one proponent has considered creating an offshore tidal impoundment in relatively shallow tidal flats to exploit components of a tidal barrage system [7].

Recent trends are for developers to examine modular systems that can be deployed incrementally at appropriate sites. Several demonstrations have been successful and others are planned (see [8]). The tidal turbine market has a potential to reach $1 billion per annum in capital expenditures by 2010, but conservative forecasts of $ 40 million per annum by 2010 appear more realistic [9]. Although several technical obstacles have been overcome, there is still a lot of work required to convince financial institutions on the rewards of tidal energy. Improved engineering of offshore structures as a result of exploration and production of oil and gas in deeper water will benefit the engineering challenge facing tidal power developers as they commercialize their technology.

A new, patented method of extracting tidal energy, the Rochester Venturi (RV), eliminates all moving parts below water, sidestepping many traditional challenges facing adoption of tidal power. Utilizing the Bernouli Principle, a novel means of extracting energy from tides relies on the fact that accelerated water drops in pressure. By accelerating the water flow into a choke, the pressure drop can be used to drive a turbine above the water surface either directly or via a secondary circuit.

The technique we have developed effectively concentrates the low-grade energy in tidal currents into the rapid flow of a lesser quantity of water in a pipe to shore. The RV approach allows for tunable efficiency. We have attained up to 24% efficiency in one design. However, high efficiency is not the primary goal, since there is so much energy available and basically no cost for fuel. In fact, to minimize environmental impact, low efficiency can even be desirable. Once environmental issues have been satisfied, the financial returns can be optimized.

The company, HydroVenturi, spun out of technology developed at London's Imperial College. HydroVenturi is primarily involved in design and development of tidal and run-of-river hydro power systems. The company firmly believes tidal power will enable communities to benefit from a durable source of renewable energy. A demonstration unit has been deployed in Grimsby, U.K.

The RV technology offers several advantages over other systems including the absence of moving mechanical or electrical components in the water. This shift of mechanical and electrical component to onshore implies less maintenance costs and readily available access to moving parts and electrical components, less expensive replacement parts and shorter downtimes.

The RV system could be submerged so that there are no visual impacts or impediments to navigation. A range of different configurations have been developed and can be tailored to a specific sites needs. The modular nature of the design allows for ease of manufacturing and the systems can be scaleable. It is anticipated that the total energy extracted will be smaller than natural fluctuations.

Our patented technology will reduce the cost of tidal power to about or even below that of gas turbines, even before the expected fiscal and legislative regimes make renewables even more attractive.

IV. ENVIRONMENT

Environmental considerations play an important role in sighting, design, construction, operation and public acceptance of any major energy development. The new technology described here has no comparable facility in place elsewhere, except for a demonstration unit in Grimsby, U.K. There is no direct applicable, practical experience to assess environmental and socioeconomic impacts. However, we can gain perspective from other similar marine activities to identify the sorts of concerns, which will likely emerge.

There are three levels of potential effects: global, regional and local. From a global perspective, tidal power is an enormous sustainable source of ultra-dense energy. The extraction of 1 MW or 1000 MW in San Francisco will not alter the earth system. There are no greenhouse gas emissions and no chemical byproducts. The tidal resource is reliable and highly predictable operating cyclically within a 24-hour period all year round. The electrical generation should not contribute in any way to global climate change.

From a regional perspective, the design of the RV system should not cause a change in sedimentation in the near field. Slight changes in tidal flow patterns in the Bay as a result of installing a RV system might lead to less intensive circulation and flushing in the south bay, but this is highly unlikely given the scale of 1 MW demonstration project. The more distal end of the bay circulation would be the place to look for a change in sedimentation rate, possible accretion of shorelines and influence on sessile invertebrates. However, it may not be measurable and it is expected to be an exceedingly minor concern. Model studies of sediment dynamics could address this issue in detail, if warranted.

The environmental impact is very dependent on the specific installation site. The impacts will occur during two phase: the installation phase and the operation phase. During construction and deployment, very specific site impacts may occur depending on the site, type of construction, methods of installation and anchoring of the system to the bottom and ecological footprint of the RV system.

Marine traffic should not be affected since the majority of the structure is below the water line and out of navigational channels. The paths for piping can be designed to minimize interference with any marine traffic or marine recreation.

Impacts on the marine life will be careful considered in the environmental impact review process, especially since marine mammals and endangered fish species are know to inhabit the bay. Unlike other tidal technologies, in the RV system there is no direct contact with turbines or obstruction of fish passages. Behavioral response of fish to the RV system is unknown. Investigation of possible provisions for screening of intakes or application of other suitable deterrent devices may be examined.

During the environmental review process, the concerns identified above will be studied and addressed in greater detail. A detailed survey of the tidal resource of the potential site including vertical velocity profile will need to be undertaken as well as a complete environmental impact review prior to a full assessment of the environmental impacts.

Fortunately, the company has deployed a test system in Port Grimsby that can be available for evaluation of specific environmental issues. Interaction of the RV system in San Francisco Bay will need monitoring to insure compliance with strict environmental codes in place in California as would be the same for any new power plant or renewable energy technology entering the California market. Once these concerns have been addressed and the system performs as designed, San Francisco can expect sustainable, renewable energy. California will then have added capacity toward its' goal of 20% renewable energy portfolio by 2017.

ACKNOWLEDGMENTS

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