Economical and Environmental Effects of Tidal Stream Power plant Using near to Queshm Island in South of Iran

Amir Bashirzadeh Tabrizi[1,*], Nassir Gifani[2]

1.Master of Science in Mechanical Engineering, Design Engineer, Water Treatment plant and Water Transmission Pipeline Department, TOOSSAB Consulting Engineers Company, Mashhad, Iran ,Research Fields: Renewable Energy, Water Treatment, Transmission Pipeline, Email: Bashirzadeh@hotmail.coim,Corresponding author.

2. Master of Science in Mechanical Engineering, Head of Department, Water Treatment plant and Water Transmission Pipeline Department, TOOSSAB Consulting Engineers Company, Mashhad, Iran, Research Fields: Renewable Energy, Water Treatment, Transmission Pipeline, Email: nssrgifani@gmail.coim.

Abstract: In this work, historical background of power generation by tidal power plants, especially tidal stream power plants across the world and types of in-stream tidal generators have been attended firstly, and then, a tidal stream site near to Queshm island in south of Iran has been studied as case study sample. According to the sample site characteristics and water velocity profile of the site, reachable energy has been estimated; in the next step, attending to reachable energy, initial investment cost, total benefit of operating period, benefit to cost ratio and other economical parameters for stream tidal power plant in case study site have been presented and power generation cost for same amount via other resources compared to the tidal-power cost. At the end, in agreement with environmental advantages of stream tidal power plants, the generated power using methods, proper solution for optimization of reachable energy from tidal streams and substituting of other power generating resources by tidal stream power plants as a major solution for energy generating in coast areas have been proposed.

Key Worlds: Tidal Streams, Tidal Stream Power-Plant, Reachable Energy, Renewable Energy

1. Introduction

Tidal power generation is about extracting clean power from a reliable and renewable energy source – the ocean. New technology is making ocean energy a viable source of power that, along with other forms of alternative energy, can supplant fossil fuels as the planet's dominant energy source [1].

Ocean energy power generation technology is in its infancy, but it is growing fast. A wide variety of devices are being built and tested by brilliant inventors and bold entrepreneurs around the globe. Energy can be extracted from the ocean in several ways; thermal gradient, salinity gradient, wave energy and tidal energy. Tidal energy technology can be further divided into tidal stream and barrage type power generation. Both wave and tidal stream technologies are at similar stages of development, with many different designs being designed and tested now. Barrage type tidal power has been in use for many years, notably in Canada at the Annapolis power plant in Nova Scotia and also in France[1].

Tidal streams may have the potential to provide significant amounts of electricity for coastal and remote island communities. As fossil fuel resources continue to be depleted, the rising costs associated with conventional power generation using diesel, natural gas, and coal may promote the economic development of renewable energy technologies, such as tidal energy conversion devices[2].

There are several ways that tidal power can be utilized as energy. One of the ways that many tidal power plants harness energy is through construction of tidal barrage. A barrage is a dam that uses potential energy, the difference in height between high and low tides. Water flows through tunnel in a dam enabling it to turn turbines, which then generates electricity. There are only a limited number of 20 sites in the world to build barrage due to the fact that it requires continuous ebbs and flow of the tides10.France is the only country so far to succeed in building a barrage power plant in La Rance. The plant can generates up to 240 Megawatts of power for its 24 turbines, which produces .012% of the necessary energy used by France[3].

Another way to harness tidal power as energy is through tidal stream generator. Similar to the way wind turbine work, tidal stream turbine uses kinetic energy to generate electricity. Selections of sites for these turbines are just as important as selections for barrages. Many different projects are currently proposed for construction of tidal stream generators since it has lesser environmental impact than barrage and it is much cheaper. The world first commercial prototype tidal stream generator, SeaGen, was installed on August 20, 2006 in Northern Ireland's Strangford Lough. It generates 1.2 Megawatts of energy to power approximately 1000 houses [3].

In stream Tidal first, introduced in the 1970s (Jones, 2005), in-stream tidal generation functions on similar principals to that of wind power. However, because the density of water is 800 times that of air, the power per unit area which is available is significantly greater than that of wind. In addition, in-stream tidal generation is a predictable resource, whereas winds change according to weather conditions. The tidal cycle is based on the lunar month, which is 29.5 days. During this cycle, tides will oscillate with a tidal period of 12.25 hours. The amplitude of the tidal oscillation is dependent on the location and geography of the area [4].

Using tidal in-stream energy to generate electricity would provide many far-reaching benefits. The primary benefit is that the construction, installation, operation, and maintenance of tidal power plants would create jobs, promote economic development, and improve energy self-sufficiency [5].

There are many compelling arguments for the use of tidal in-stream energy conversion technology. First, with proper sitting, converting tidal in-stream energy to electricity is believed to be one of the more environmentally benign ways to generate electricity. Second, since kinetic energy is a function of the density of the moving mass and its speed and water has high density, the power density of the tidal resource is high. Third, in- stream tidal energy offers a way to minimize the aesthetic issues that plague many energy infrastructure projects, from nuclear to coal and to wind generation. Since most tidal in-stream energy conversion devices are totally submerged they are not visible. Although variable in power level like many other renewable resources, tidal energy is predictable and therefore can be more easily integrated into the electricity grid for providing reliable power [5]. In-stream tidal energy is an important energy source and deserves a fair evaluation of its potential to add to the energy supply mix of Iran.

1-2- **Types of In-Stream Tidal Generators**

As in-stream tidal generation operates similarly to wind power, many designs share configurations with wind turbines, with changes to dimensions and shapes to more efficiently operate with the higher fluid density and lower speeds. The most common configurations are axial turbines, cross flow turbines and oscillating devices[4].

-Axial Turbines

Perhaps the most common in-stream turbines, axial turbines are very similar to the modern wind turbine. Figure ١.1 shows various configurations of in-stream axial turbines.

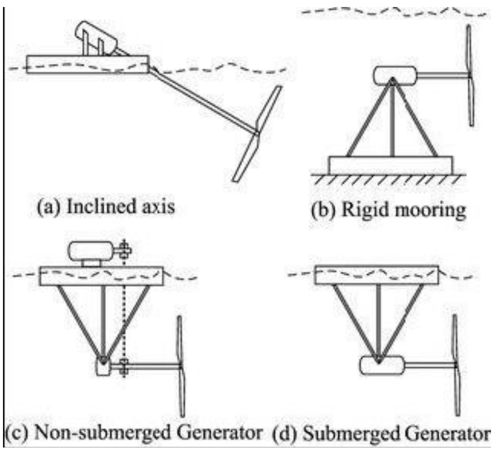

Figure ١.1: Axial turbine designs

As the moving water propelled by winds, temperature, salinity levels, and Coriolis force passes into the duct, it is forced along the rotor blades creating rotation. The rotation of the rotor can then be turned into electricity by use of the generator. Electricity is then transferred to the closest grid input. The rotation of the rotor blades is "slow" and the tips are contained within the outer housing, eliminating potential danger to aquatic life. The open center of the turbine was designed also as an environmental preservation measure, allowing aquatic life to pass through and also increasing efficiency.

-Cross-flow Turbines

Cross-flow turbines operate on similar principals of axial flow units, however as the name suggests, the flow of water passes across the axis of revolution. Figure 1.2 shows various designs of cross-flow turbines.

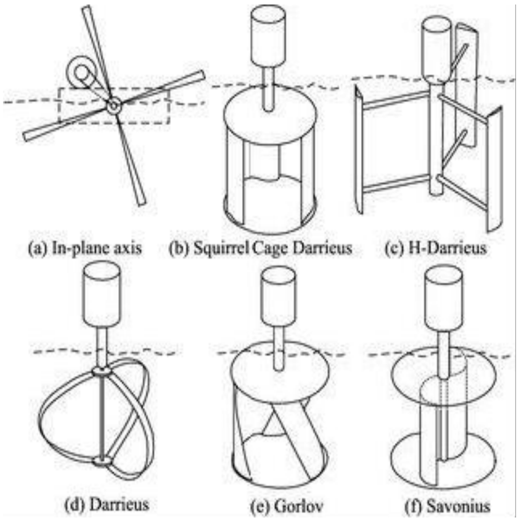

Figure 1.2: Cross-flow turbine designs

Like vertical wind turbines, cross-flow designs are not dependant on a specific direction of stream flow. However, in most tidal applications, the stream direction is constant for each cycle.

-Oscillating Devices

Oscillating devices use the hydrofoil design not to directly rotate a shaft, but to create oscillating movement, which in turn drives a generator, creating electricity. These devices work on similar principals to both axial and cross-flow turbines, whereby the power is a function of the speed of the stream. Like other forms of in-stream tidal generation, oscillating generators having no impact of water levels or flow[4].

2. Studied Tidal Stream Site Near to Queshm Island in South of Iran

The proposed location is Queshm neck between Pohl port in suburb of Bandar-e-Abbas and Laft port in Queshm Island in south part of Iran(Figure 2.1 shows the Images of location which extracted from Google earth).

Figure 2.1.a - Studied tidal stream site near to Queshm island

Figure 2.1.b - Studied tidal stream site near to Queshm island

The neck width is almost 2200 m and its depth is almost 22 m. The average water velocity in the neck is about 2 m/s.

Now, the government is planning to build a bridge between Pohl port in suburb of Bandar-e-Abbas and Laft port in Queshm Island to connect the main area of the country to the island and it is looks that after finishing of the bridge construction the truism industry will be expanded and supply of energy will be one of most important issue in the region.

3. Reachable Energy

Estimation of energy generating potential for a location or power-plant installation capacity is the most important issue in tidal stream power-plant investment which is calculated by following equation [1]:

$$P_{extractable} = N_{units}\,\eta \frac{1}{2}\,\rho\, A_{turbin}\, U^3 \qquad (١)$$

Where N_{units} is the number of installed units, η is the turbine/mechanical/electrical efficiency, ρ is the density of water (kg/m^3), $A_{turbine}$ is the turbine rotor area (m^2) and U is the instantaneous current velocity (m/s). It can be seen that power is proportional to the area swept by the turbine, so at a given site, devices that present a similar area will have similar power potential. Then, the difference between devices is the efficiency which the device extracts the power from the water flowing through it – this is the battleground for the device developers.

A very significant observation from the formula is the importance of current velocity to power. Because velocity is cubed in the formula, higher velocities confer an ever-greater power advantage, thus the importance of site selection.

η where is the power coefficient , is a measure of the overall hydrodynamic efficiency of the device and this will depend on the tip speed ratio (blade tip speed to current velocity). The theoretical (Betz) maximum efficiency is 0.59 that practical values lower than it[6]. In average, the value of η is considered as 0.40 in this research and ρ is 1027 kg/m^3 (see water); therefore equation (2) changes to simple following form:

$$P_{extractable} = 206 N_{units} A_{turbine} U^3 \qquad (2)$$

Attending to equation (2), water velocity , turbine rotor area and the number of installed units are three important factors in energy generating by tidal stream power plant.

At the studied site, three bladed horizontal axis axial flow turbines made by Verdant Power Company is attended as in-Stream tidal generators. Verdant Power is a US based company that has developed and tested several tidal stream turbine devices. The company settled on a design that uses a three bladed horizontal axis axial flow turbine. Figure 3.1 at below shows the nature and scale of the devices [5].

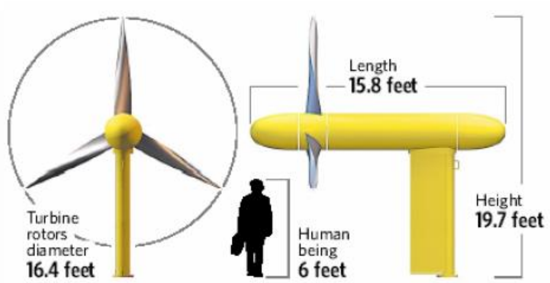

Figure 3.1- Nature and scale of device

According to neck width and geographical characteristic of the site, at least 150 numbers of introduced devices can be installed at the site. Therefore, with attending to equation (2) and regarding to average water velocity, turbine dimensions and number of turbines, the site extractable power is as below:

$$P = 206 * 150 * 19.62 * 8 = 4.85 MW$$

4. Economical Evaluation

In tidal stream power-plant evaluation, cost and income of the plan, capital return time, generated power value and capital internal efficiency rate, are final indicator for complete comparing of different components; to price estimate of energy unit generated by tidal stream power-plant, initial investment cost is one of the main effective elements which should be determine properly.

Initial and operational investment estimation of tidal stream power-plant have been done based on economical calculation of several operating power-plants, study of several tidal stream power-plants and different country experience; average initial and operational investment cost of tidal stream power-plants for three samples in different countries have been proposed in table 4-1. The first and second row are investment and operational cost of Alaska tidal power system and Nova Scotia tidal power system which is calculated and estimated by EPRI(Electrical Power Research Institute) at design phase[1]. Within the past few years the EPRI completed a survey of possible tidal energy locations in Maine (and other areas), and the Western Passage was one of the sites examined. Analysis of the performance and economic feasibility in the Western Passage is included of two turbine designs: Lunar Energy's Rotech Tidal Turbine (RTT), and Marine Current Turbines' (MCT) SeaGen. The third row in table 4-1 shows investment and operational cost of MCT commercial plant in the Western Passage[7].

Table 4-1- Average initial and operational investment cost of tidal stream power-plants for three samples

Site	Size (Mw)	Equipment	Installation	Total	Per Kw
Alaska	0.76	1,720,670	1,442,000	3,162,670	4161
Nova Scotia	1.1	2,178,000	1,442,000	3,620,000	3258
Western Passage	1.15	1,633,000	1,099,400	2,734,700	2378

2000 US dollar per Kw is attended by EPRI as average capital cost of commercial tidal stream power plant [7]; in addition, following elements, also affect the final price of tidal stream power-plants in different countries; access rate, labor cost, geographical condition, material cost, dollar exchanging rate and transportation cost are the components which can result to some variations in final cost. In this work, 2000 US dollar per Kw is attended too, for calculation of capital cost for studied tidal stream power plant near to Queshm Island and annual maintenance costs are estimated to be approximately 4% of the capital cost for commercial size systems [1].

By attention to power price in Islamic Republic of Iran annual budget (2008-2009) which is 0.0742 $ for each kilo-what-hour of power and 25 year operation for tidal stream power plant, the benefit to cost (B/C) ratio of attended power-plant can be calculated; Table 4-2 presents the estimated cost of initial investment, operation, income cost and B/C ratio for proposed power-plants. Because this power-plant will be installed in a neck ,the tidal stream power-plant can work in the whole year but, it is intrinsic that the plant needs the time for service and maintenance. By attention to the this fact that the overhaul time of tidal stream power-plant usually is low, the total time which the plant will not work is about 5 weeks per year(the time that the plant will not work because unusual accident is not attended).

Table4-2. Estimated cost for proposed power-plant (*10^3 $)

Item	Cost		
Power-Plant Investment Cost	9700		
Annual Operation Cost	388		
Generated Power Annual Income	2850		
Interest Rate (%)	٨	١٠	١٢
Operation Cost for 25 Years (present worth)	4142	3522	3043
Total Cost (present worth)	13842	13222	12743
Total Income of Generated Power for 25 Years(present worth)	30425	25871	22354
B/C Ratio	2.2	1.96	1.75

Figure 4.1shows the B/C ratio at different interest rates for studied stream tidal power-plant.

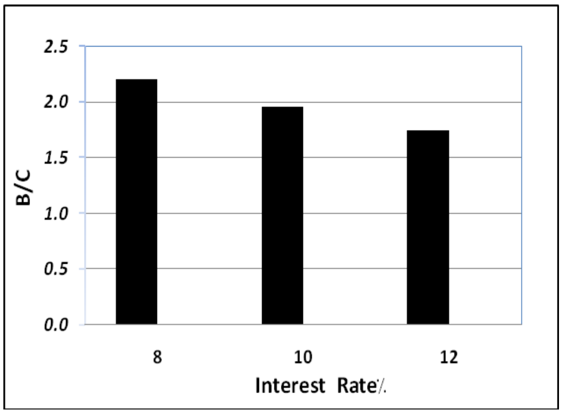

Fig.4.1 -B/C ratio at different interest rates

5. Substitute Energy Cost

In this section, substitute of proposed tidal stream power-plant in studied area by diesel generators which have the same power have been studied and analyzed economically. Because in many cases, tidal stream power-plants use in the situation which can not be supplied by power network because of economical reasons, the power generation by diesel generators has been attended as substitute method. Provided data in table 5.1 have been used as basic data for economical evaluation of diesel generator [8].

Table5.1- Basic data for economical evaluation of diesel generator

Diesel Generator Initial Investment Cost	200$ per KW
Conversion Rate	2.8 kwh per Liter of Diesel
Diesel Cost	0.35$ per Liter

Table 5.2 shows, estimate cost of initial investment, operation and fuel consumption in 25 year operation period for substitute of proposed tidal stream power-plant near to Queshm island in south of Iran by the same power diesel generators (assume 5 weeks per year for generator overhaul).

Table4. Estimate cost for substitute of proposed power-plant by the same power diesel generators (*10^3 US$)

Item	Cost		
Diesel Generator Initial Investment Cost	970		
Fuel Annual Cost	4801		
Operation Annual Cost	48.5		
Interest Rate (%)	٨	١٠	١٢
Fuel Cost for 25 Years (present worth)	51255	43584	37659
Operation Cost for 25 Years (present worth)	518	440	380
Total Cost (present worth)	52743	44994	39009

In figure 5.1, final cost of supply, installation, construction and 25 year operation (present worth) for proposed tidal stream power-plant and same power diesel generators have been compared at different interest rates.

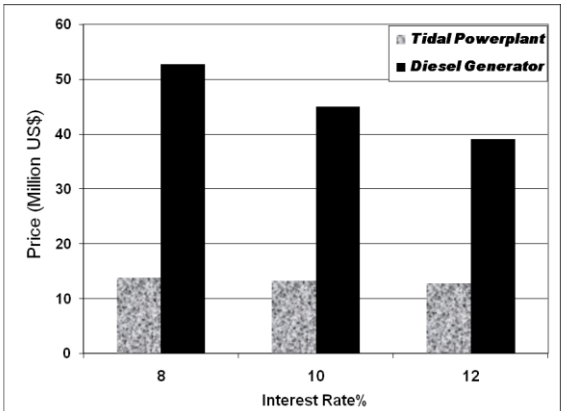

Fig.5.1 Final cost of establishment and 25 year operation of proposed power-plant and same power diesel generators at different interest rate

6. Environmental Advantages of Generated Power by Tidal Stream Power-Plant

Today, the wind turbines, small hydro power-plants and tidal stream power plant can have the important role in renewable energy generation; in the other hand, energy generation by tidal stream power-plants doesn't result to CO2 emission and other environmental pollutions. In fact, tidal stream power-plants can act as stable and safe resources of renewable electrical energy; in additional, tidal stream power-plants don't need to huge water dam or huge water reservoir construction and affect the environmental cycle of installation location so lightly[1].Study of tidal stream sits in Iran, shows that notwithstanding of acceptable and proper tidal stream site existing in Iran, using of this kind of renewable energy has not been attended practically in Iranian energy policy; by using of tidal stream power-plant in proper sites, huge amount of energy is reachable and the power can be supplied to the villages or small town around the site. Also, most of the proper sites for tidal stream power plant establishment are in the areas that usually are attended as tourist attraction places and there are many tourist facilities in these areas; the energy which will be provided by tidal stream power plants can supply the demand of these places or used as supplementary power generation in season demand pick. As an example, Queshm island is one of the most attraction places that every year many tourists from across the Iran visit the island, especially at spring and there are lots of hotels, market centers and other tourist facilities in the island; total demand of Queshm island is almost 160 Mw that the proposed tidal stream power plant can cover the residential area near to north cost easily or can be used as supplementary power plan to cover the pick demand of the area.

7. Conclusion

Study of tidal stream power-plant history, shows that using of this kind of power-plant as one of renewable energy resources is increasing. In the other hand, as it was presented in economical evaluation section, the B/C ratio of tidal stream power-plant establishment for studied case is about two and, the B/C ratio increases by water velocity increasing of the plant sensitively; Because of the low initial investment cost and slight operation cost of tidal stream power-plants, their installation at a proper site with suitable velocity in most of the cases, even in low installation capacity is economical. Also, tidal stream power-plants are the safe and stable sources of electrical energy generation which with light impact on environmental cycles are clean electrical energy generators. Therefore, recognizing of tidal stream sites with proper water velocity and installation of tidal stream power plants can be resulted to huge amount of energy generating; therefore, tidal stream power-plant using, especially in countries which have long coast lines and sea areas such as Iran, should be considered technically and economically at national energy policy.

8. References

[1] A. Enayati, S. Kazemneghad, Small Hydro Power-plant Using in Mazandaran, Mazandaran Regional Power Company, Iran, 2005.

[2] O. Tsymbalenko, Y. Vikhorev, Small Hydro-energy Raise Market Prospects, Green Energy Conference, Ukraine, 2005.

[3] IEEE Guide for Control of Small Hydro Electric Power Plants, IEEE Std 1020, 1988.

[4] J.L. Gordon, P. Eng, Turbine Selection for Small Low-Head Hydro Developments, Hydropower Consultant, Organized by: Natural Resources Canada at Water Power XIII, Buffalo, New York, U.S.A., July 29, 2003.

[5] M. Moradi, Economical Evaluation of Small Hydro Power-plant, Saharif University of Technology, Tehran, Iran, 2006.

[6] M. Vaghefi, G. Derakhshandero, Hydro-energy Optimization in Small Hydro Power-plant, Water Resource Management First Annual Conference, Tehran, Iran, Nov 2004.

[7] Sigma Engineering Ltd.; Canadian Small Hydro-Power Handbook, Canada Center for Mineral and Energy Technology, Energy, Mines and Resource Canada, November 1991.

[8] European Small Hydropower Association; Guide on How to Develop a Small Hydropower Plant, ESHA 2004.

[9] I. Winkler, Small Hydropower Resources and Prospects of Small Hydropower Electric Plants in the Near-Border Regions of Ukraine, Chernivtsi National University, Ukraine.

[10] T. Bruno, the Need for a New Approach to Hydropower Financing, HRW, Volume 12, number1, pp. 22-29, March 2004.

[11] The value of small hydro, Water Power, Volume 57, Number 10, pp. 26-30, October 2005.