Technical Economic study for Electricity Production by Using (Tidal- Hydrogen) in Socotra Island, Yemen.

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Abstract. The great need to use electricity at present and to ensure its continuity in future requires finding renewable and sustainable sources; the best of those sources are renewable energy sources such as wind energy, solar energy, and tides. All research focuses on studying those sources for each region to give the complete database that can rely upon in future to build projects generating electric power according to accurate scientific studies, specifically in areas far from the main electricity grid, such as remote islands, including Socotra Island, which, like other Yemeni cities, suffers from a severe crisis to access electricity. Energy storage is a natural thing when using renewable energy due to seasonal change, daily and hourly in these sources; one of the best ways of storing is the production and storage of hydrogen for use at peak periods or any other benefits. Economic information is still incomplete about the production of electricity by hydrogen, especially in the Middle East region, which considers that the primary source of electricity is only fossil fuels. This paper gives a study of the level of tides on Socotra island, and a technical study of the possibility of producing electricity using this renewable source according to its efficiency, and an economic assessment of electricity generation by (Tidal-Hydrogen) for this island.

Keywords: Renewable Energy, Tidal Energy, Hydrogen production, Yemen.

1 Introduction

Concern is increasing due to pollution resulting from the use of fossil fuels to produce energy, due to the problems caused by the combustion of that fuel, which leads to an increase in the proportion of carbon dioxide that spreads in the air in addition to the high rate of global warming and the expansion of the ozone hole. The European Union has decided that the use of fossil fuels should be reduced to 20% and reduce the emission of carbon dioxide that is by relying on energy production from renewable sources, and that plan has been Implemented from 2009 to 2020, and these goals are binding even after 2020[1].

Tidal energy is one of the sources that can exploited for the production of electricity, scientists and developers have focused on how to use this energy to produce electricity at the lowest costs. The costs have decreased significantly from 2010 to 2020 as the capital costs have decreased by up to 50%. Emphasis must be placed on it to generate electricity and also to use it in the storage process to use it at a time of low tide generation. The capital costs estimated by IRENA from 117 to 800 $/kW [2], but these costs are only the costs of tidal turbines and the total costs of turbine facilities differ according to the type and method for producing electricity, either dams, barriers or other types of turbines, each technique has costs that differ from the other, this difference becomes apparent upon knowledge of Levelized Cost Of Electricity (LCOE), which ranges from about 0.26 to 050 $/kW in 2014 (LCOE can calculated by Equation (1))[3].

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \quad (1)$$

Where It = investment expenditures, Mt operations and maintenance expenditures in t, Ft = fuel expenditures, Et electricity generation, r = discount rate 6%, and n = system economic life = 20 years.

In this paper, the focus will be on the evaluation of electricity price according to modern prices 2020, despite the difficulty of obtaining information during that period as a result of the economic recession that

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energy sources witnessed as a result of the Corona epidemic, but that information was collected and analyzed to give a modern and a clear vision for electricity production by tidal energy, as well as the economic evaluation of storage by producing hydrogen, which is considered a renewable and environmentally friendly source of energy.

2 Site Information

Socotra is Yemen island and considered within the Hadramawt governorate, located in the Arabian Sea, 250 km east of Africa Horn and 350 km south of Arabian Peninsula. It has an area of 3,600 m^2 and height above sea level is 257 m. located in the map is between two latitudes (12.18^o - 12.24^o) north of the equator, and longitudes (53.19^o-54.33^o) east of Greenwich[4][5][6].

3 Tidal Energy in Socotra

Tidal energy is a type of renewable energy source, as a tidal movement in oceans is converted into electrical energy by tidal turbines; the main reason for tidal phenomena occurrence is the influence of Moon and Sun gravitational to ocean water, being the weakest substance on Earth, it mentioned that the influence of Moon gravitational to Earth is greater than the influence of Sun gravitational on Earth because Moon is closer to the Earth, It is worth noting that there are two rises and two retreats in water level daily, in addition to that when Sun, Earth, and Moon are in a straight line, the tide increases[7][8].
Tidal energy can exploit by using turbines, where water passes through turbines that work to generate electricity by converting the kinetic energy of water into electrical energy. Tidal power generators can exploit in three different ways. First are tidal currents, it defined as a fast-flowing body of water resulting from tides where turbines placed in these currents, and when tidal generators used, they produce an electric current. Second is dams or reservoirs, this done by installing turbines in gates of dams to generate tidal energy, where ocean water currents pass through dam gates while it rises tide, then these gates close when water reaches its highest height, resulting in a lake or a pond, and then the water is released through the turbines, that lead to power generation and control. Third, tidal lakes, an important way to generate power by building large tidal lakes, which is a large mass of ocean water surrounded by a natural or artificial barrier, turbines generate this energy while filling and emptying the lakes[9].
Previous studies show that Socotra Island lies within a tidal range between 1.5 to 2 meters, as in Figure (1), which shows the global map of the tides [2].
From the obtained information, the annual tide average on Socotra island reaches heights between 1.6 m and 2 m. Figure (2) shows the average values of the tide during past years, showing the change in tide levels. In case of accurate study for periods less than a year, information details will be clearer. Figures (3) show a detailed drawing to clarify all details during those seasons and noted that in January, the average tide level ranges between 1.5 to 2 m, especially from eastern and northern sides of the island, and 1 m on the western side. This value changes until it reaches about 1 m in April. Then, the tide rate increases until it reaches its largest value in July, where the tide is 5 m on the south and southeast sides, 4 m on eastern and western sides, and 3 m on the northern side. In October tide reach approximately 1.5 m on south and 1m on north side.

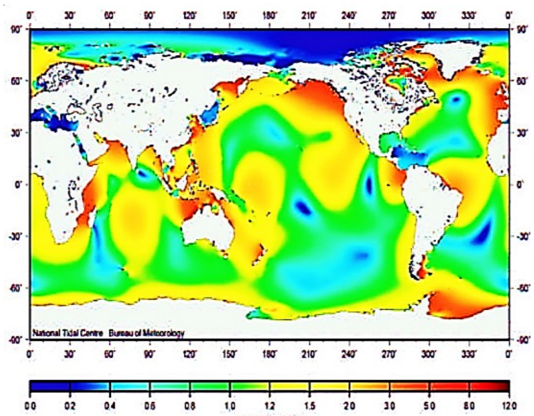

Fig. 1. Global tidal in map.

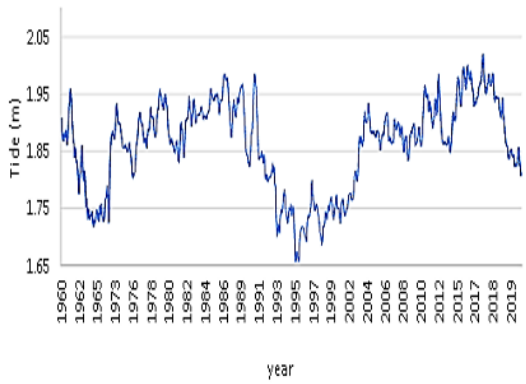

Fig. 2. Tide for 60 years ago in Socotra.

Figure (4) shows daily detail of tide on Socotra island for January (2019), a lower and higher process in tide is evident in its levels where the difference is significant in first three days. The difference begins to decrease from the fourth day until seventh, forming what is called neap tide, then difference begins to rise from 8th to 18th, to create a spring tide and begins to decline to create a neap tide. Thus, in one month, there are two highs and dips in tide according to the movement of moon, sun, and their alignment.

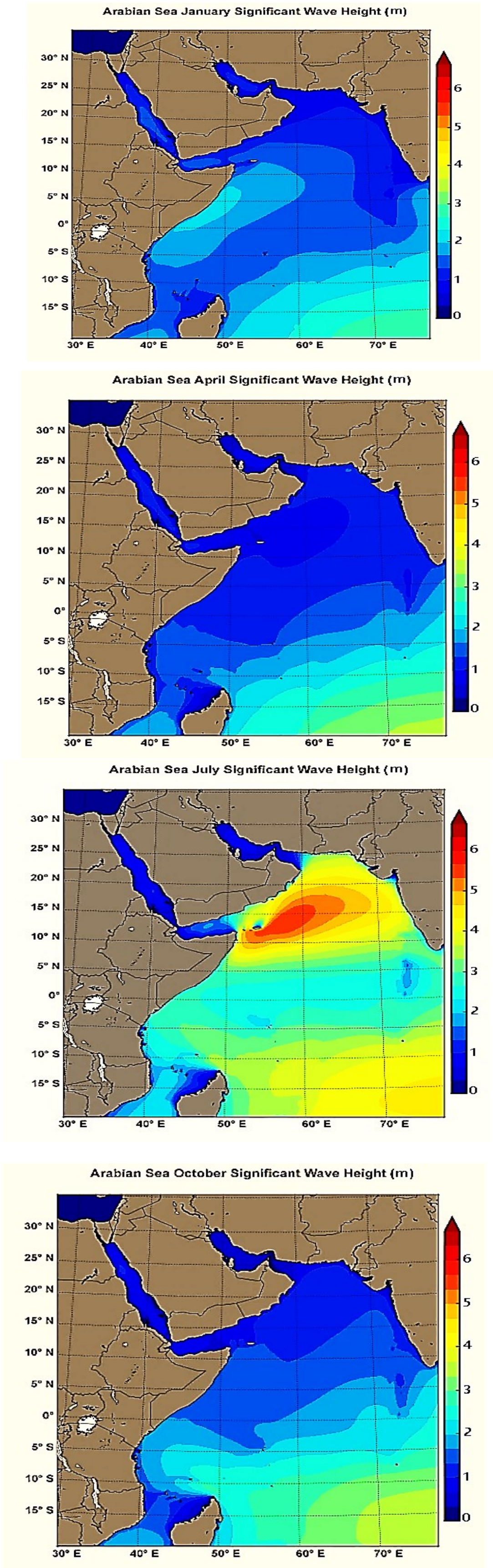

Fig3. Seasonally tidal in Socotra.

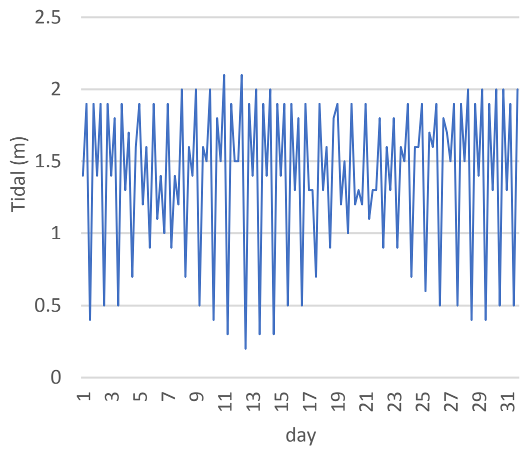

Fig. 4. Tide for one month.

4 Economic Study for Tidal

The capital and installation costs of tidal turbines differ according to manufacturers, operating and installation costs, a significant reduction in those costs has been observed since 2010 until the last year 2020, as capital costs decreased from 10,000 $/kW to5,000 $/kW, as a result of the technological development in manufacture, installation of these turbines, and those costs reduced whenever the production capacity is greater than 1000 MW, it should note that the cost of electricity production in these turbines is affected by sea waves height in addition turbines generation efficiency. Table (1) shows capital costs for installing high-capacity turbines, also shows additional variables such as maintenance and operating costs, Port activities, and other costs through which electricity can generated to cover the region's need for electricity, which is estimated at 80 MW per year [2][10].

Table 1. Tidal turbine installation cost.

Parameter	Cost	Unite
Capital Cost	5000	$/kW
O&M	50	%
Other cost	12	%
License fee	4	%
Port activity	31	%

5 Hydrogen Storage

Energy storage methods in an off-peak period are considered one of the necessary means to provide electricity, especially when dealing with renewable energy sources, as they are unstable and change from time to other time. the best way to store energy is hydrogen production by analyzing water, where the green hydrogen produced from renewable sources is one of the best methods that have gained concentration Researchers and scientists to take advantage of it in the future to energy production, move vehicles and other uses. The process of storing and producing hydrogen goes through several stages, starting from the analysis of water by the proton exchange membrane (PEM), where the water analyzed into its essential compounds, hydrogen and oxygen, then the hydrogen is stored, then must to hydrogen storing, the more economic method is hydrogen storage in compressed gas state, when need to use hydrogen to produce electrical energy, it can use fuel cells, where electricity produced inside fuel cells with the presence of oxygen. Thus, the stored hydrogen can used for electricity production. This method is considered clean and non-polluting because its output is only electricity and water. Table (2) shows the costs of each device used to produce, store and use hydrogen. The costs have calculated for a 20-year lifetime, and all these values considered recent, taken in 2020. It should note that to produce 1 kg of hydrogen, it needs energy estimated at 50 kWh and that the energy produced from 1 kg hydrogen is 39.4 kWh [5] [9]to[12].

Table 2. Cost detail for production, storage, and using hydrogen.

PEM cost	Cost	Unite
Capital Cost	1100	$/kW
O&M	5	%
Other costs	10	%
Hydrogen Storage	Cost	Unite
Capital Cost	500	$/kW
Compression 700 bar	20	%
O&M	6	%
Other costs	10	%
Fuel Cell	Cost	Unite
Capital Cost	1400	$/kW
O&M	3	%
Other costs	5	%

6 Result and discussion

All information about tides state of Socotra island shows that it can used to produce electric energy, but with an efficiency that is not great, reaching 25%, because the level of tides did not reach great heights of up to 5 m except in some months (July and August), but it can cover region needs as is the case in New Zealand, where sea level rises are close to those in Socotra Island; also hydrogen can used to store energy and used to produce electricity when needed, and when applying economic studies to produce electricity in order to calculate LCOE by Equation (1), it noted that the cost of producing electrical energy by tidal turbines is 0.25 $/kWh, Table (3) shows the detailed costs used in the project.

Table 3. LCOE detail for Tidal energy in Socotra.

Parameter	**Cost**	**Unite**
Capital Cost	0.11	$/kWh
O&M	0.055	$/kWh
Other costs	0.01	$/kWh
License fee	0.0044	$/kWh
Port activity	0.035	$/kWh
Capacity Factor	25	%
LCOE	**0.25**	**$/kWh**

Hydrogen production and storage is economical, inexpensive, one of the best ways to use, especially with the current development of hydrogen production and storage equipment, as it reached low values by 2020, Table (4) shows the costs of producing and storing hydrogen and calculating LCOE for each phase that passes for hydrogen production, due to the high price of the electrical energy source resulting from Tidal, the cost of producing 1 kg of hydrogen reaches 9 $/kg, this value decreases with the lower cost of the electricity price.

Table 4. LCOE for Hydrogen production.

Parameter	**Cost**	**Unite**
PEM	0.02	$/kWh
Hydrogen Storage	0.018	$/kWh
Fuel Cell	0.012	$/kWh
LCOE	**0.05**	**$/kWh**

With these results, the total costs of energy consumed from tidal energy can deduced by summing the costs of producing electricity, producing, storing and transmitting hydrogen, we will notice that it reaches 0.3 $/kWh, which is not an expensive cost compared to the price of electricity currently generated on the island, where the cost reaches more than 0.3 $/kWh in peak.

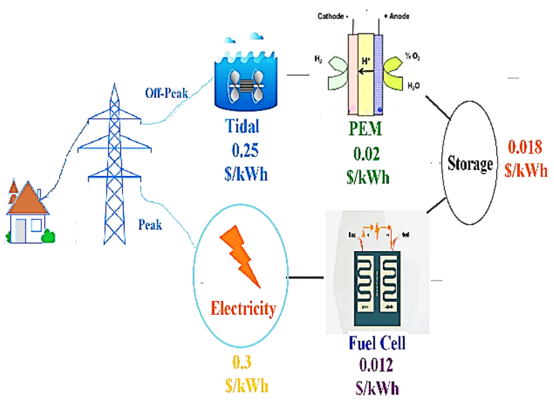

Fig. 5. LCOE for every stage in electricity production in (Tidal – Hydrogen) System.

7 Conclusion

By studying the obtained information on Socotra Island, it becomes clear that it contains natural sources of energy, like tidal energy, which is a renewable and clean source, through which energy can produced permanently and environmentally friendly. By statistical study and physical application of all information obtained, the following appears:

1. Tidal ratio in Socotra island shores has values between 1.65 to 2 meters, and these values vary according to moon movement seasonally and daily.
2. Due to the tide less than 5 m, the efficiency of electricity production less 25%,
3. The cost of producing and storing hydrogen is 0.05$/kWh of the total cost of producing, storing, and electricity production by fuel cell, which is a low cost of electricity storage, but due to the high price of electricity resulting from tidal power, the price per kilogram of hydrogen is 9 $/kg.
4. Total cost of producing and storing hybrid electricity between (Tidal-Hydrogen) for Socotra is 0.3 $/kWh (Using in peak consumption period).

REFERENCES

[1] E. Segura, R. Morales, and J. Somolinos, “Cost Assessment Methodology and Economic Viability of Tidal Energy Projects,” *Energies*, vol. 10, no. 11, p. 1806, Nov. 2017, doi: 10.3390/en10111806.

[2] “Tidal Energy Technology Brief,”. IRENA Ocean Energy Technology Brief 3 June 2014.

[3] T, Araquistain. “Master Thesis_ TIDAL POWER_ Economic and Technological assessment Tatiana Montllonch.” Department of Thermal Engineering Tsinghua University.

[4] S. Serag and E. Adil, “Environmental Physics Study of Natural Renewable Energy Resources in Socotra, Yemen,”, INDONESIAN JOURNAL OF SOCIAL AND ENVIRONMENTAL ISSUES (IJSEI) April, 2021.

[5] S. Serag, O. Elbakkali, and A. Echchelh, “Economic Comparison Between Two Hybrid Systems (Wind-Hydrogen) and (Wind-Hydroelectric) for Electricity Production in Socotra, Yemen,” in *Digital Technologies and Applications*, vol. 211, S. Motahhir and B. Bossoufi, Eds. Cham: Springer International Publishing, 2021, pp. 1341–1351. doi: 10.1007/978-3-030-73882-2_122.

[6] S. Serag, K. Ibaaz, and A. Echchelh, “Statistical study of wind speed variations by Weibull parameters for Socotra Island, Yemen,” *E3S Web Conf.*, vol. 234, p. 00045, 2021, doi: 10.1051/e3sconf/202123400045.

[7] A. G. Abubakar, M. R. Mahmud, K. K. W. Tang, A. Hussaini, and N. H. Md Yusuf, “A REVIEW OF MODELLING APPROACHES ON TIDAL ANALYSIS AND PREDICTION,” *ISPRS - Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.*, vol. XLII-4/W16, pp. 23–34, Oct. 2019, doi: 10.5194/isprs-archives-XLII-4-W16-23-2019.

[8] “Tidal energy advantages and disadvantages: key points to consider.” https://www.power-technology.com/features/tidal-energy-advantages-and-disadvantages/ (accessed Jan. 18, 2021).

[9] B. Polagye, B, Cleve, A, Copping, K, Kirkendall “Environmental Effects of Tidal Energy Development,”, Proceedings of a Scientific Workshop March 22-25, 2010.

[10] M. St, “2016/ARP002 - The Tidal Turbine Reef (TTR) Feasibility Study,” ARENA Tidal Turbine Design Report, 2016.

[11] A. Gupta, “Hydrogen Storage, Distribution and Cleaning,” DEGREE PROJECT IN CHEMICAL SCIENCE AND ENGINEERING, SECOND CYCLE, 30 CREDITS STOCKHOLM, SWEDEN 2017

[12] Z. Luo, Y. Hu, H. Xu, D. Gao, and W. Li, “Cost-Economic Analysis of Hydrogen for China’s Fuel Cell Transportation Field,” *Energies*, vol. 13, no. 24, p. 6522, Dec. 2020, doi: 10.3390/en13246522.

[13] C. E. G. Padro and V. Putsche, “Survey of the Economics of Hydrogen Technologies,” NREL/TP-570-27079, 12212, Sep. 1999. doi: 10.2172/12212.

[14] J. Yates, “Techno-economic Analysis of Hydrogen Electrolysis from Off-Grid Stand-Alone Photovoltaics Incorporating Uncertainty Analysis,” October 2020 doi: 10.1016/j.xcrp.2020.100209.