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WAVE ENERGY AND TECHNICAL POTENTIAL OF TURKEY

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Abstract

As long as it is economical, Turkey, which is encircled on three sides by the seas, should have the utmost benefit of using her existing potential of the wave motion. This paper presents our assessment on whether it is feasible to integrate the wave energy systems into the current Turkish Energy Program. The data required for calculating the approximate wave energy densities at many sites along the Turkish coasts have been derived from "Wind and Deep Water Wave Atlas of the Turkish Coast", MEDCOAST Publications, have been used in a wave energy project analysis, which has been conducted by using RETScreen® International, "Small Hydro" in order to find out the cost effectiveness of a wave power converter system to harness the sea power from Turkish waters having a mild climate. The technically available resource has been estimated approximately 10 TWh/year with an annual wave power between 4 and 17 kW/m. This is 7.8 % of the economically feasible potential of current

Turkish hydroelectrical energy. The regions in the west of the Black Sea in the north of Istanbul Straits and off the southwestern coasts of Aegean Sea between Marmaris and Finike have been suggested as the best sites to harness the wave energy.

DALGA ENERJİSİ VE TÜRKİYE TEKNİK POTANSİYELİ

Özetçe

Ekonomik olduğu sürece, üç tarafı denizlerle çevrili olan Türkiye, mevcut dalga hareketi potansiyelinden en üst seviyede fayda sağlamalıdır. Bu makalede, mevcut Türk Enerji Programına dalga enerji sistemlerinin entegrasyonunun mümkün olup olmadığı değerlendirilerek sunulmaktadır. Türk kıyılarında birçok mevkide yaklaşık dalga enerji yoğunluğu hesaplamak için gerekli veri MEDCOAST Yayınlarının "Türk Sahilleri Rüzgar ve Derin Su Dalga Atlası"ndan elde edilen veri, "RETScreen ® International" tarafından geliştirilen "Küçük Hidro" dalga enerjisi proje analizinde kullanılarak ılıman iklime sahip Türk sularında deniz gücünden faydalanmak maksatlı bir dalga enerji çevirici sisteminin maliyet etkinliğini bulmada kullanılmıştır . Yıllık 4 ile 17 kW/m dalga gücü arasında teknik olarak emre amade kaynak yaklaşık 10 TWh/yıl tahmin edilmektedir. Bu potansiyel,mevcut Türk hidroelektrik enerji potansiyelinin ekonomik olarak %7.8'sidir. İstanbul Boğazı kuzeyi Batı Karadeniz bölgesi ve Ege Denizi'nin güneybatı kıyılarında Marmaris ve Finike arasındaki bölgeler, dalga enerjisinden koşum için en iyi mevkiler olarak önerilmiştir.

Keywords: Wave energy; Captured wave power; Wave height.
Anahtar Sözcükler: Dalga enerjisi; Elde edilen dalga gücü; Dalga yüksekliği.

1. INTRODUCTION

It seems that the most important challenge, which the whole world has encountered up to now, is the loss of environmental balance caused by the fast and too much consumption of fossil fuels accumulated under the earth's surface in millions of years throughout the world's life. It may be reasonable to expand the variety of the renewables to provide the most of the non-peak energy need while environmental concerns are rising.

In terms of planning the energy of far future, that the politicians, manufacturers, designers and end-users' desire for meeting the fixed and small scale energy needs from the renewables will give a chance to help to spare the nuclear and fossil sources and sub-products based on them for the future generations. Before the conventional sources finished completely, the sun and other clean and unlimited energy resource forms of it might seem to be used widely in the next centuries. Wave energy may be one of the renovating processes, since sea wave has more energy density than other renewables such as wind and solar.

Wave energy devices are designed mostly in three groups according to where they are established; shoreline, near shore, and offshore (> 40 m depth) [1] and in two processes: those heaving, surging, pitching, squeezing and moving to all directions by the waves and those reservoir type of devices holding the sea water above the mean sea level.

Turbine driven generators generate electricity. Mostly used wave energy converters (WECs) are;

Turbines coupled with an oscillating water column (OWC), can be given as below;

Wells type turbines:

- Wells turbine with guide vanes (WTGV);
- Turbine with self-pitch-controlled blades (TSCB);

• Biplane Wells turbine with guide vanes (BWTG);

• Contra-rotating Wells turbine.

Impulse turbines:

• Impulse turbine with self-pitch-controlled guide vanes (ISGV);

• Impulse turbine with fixed guide vanes (IFGV);

• Mc Cormick counter-rotating turbine.

• Radial turbine:

• Cross flow turbine;

• Savonius turbine [2,3]

The run-up type WECs, the kinetic energy of the sea waves is used to store seawater in a reservoir using low-head water turbine such as;

• Propeller type with fixed blades,

• Semi-Kaplan type with fixed guide vanes and

• Unregulated on/off turbine with fixed runner blades and fixed guide vanes. [4]

A variety of wave energy devices are around the globe, being used to research and being developed in Europe, Japan, The United States, Canada, South Africa, Israel and other countries. Some of the devices are declared to be getting commercial and others are precommercial (Limpet wave energy converter on Islay, Scotland [5], or shoreline, Oscillating water column, OWC at the Azores [6], the Pelamis system in the UK [7], The Archimedes Wave Swing, AWS, off Orkney [8], The Wave Dragon in Nissum Bredning, Denmark [9], The Sea Dog in the Gulf of Mexico [10]) Many other projects have been produced recently.

Energy storage, desalination, irrigation, fisheries cultivation and providing electricity directly to the grid system are in the wave power usage areas. Pumping liquidified mixtures from the sea depths and producing hydrogen can be the important options in the future.

Taking into account the environmental sensitivity, wave energy is expected to reduce the dependence on fossil fuels in producing electricity. As the technologies of conserving, carrying and using hydrogen develop, wave energy converters can produce hydrogen and so the adverse environmental impact occurred during meeting the need for energy can be decreased at a definite level. This will help to decrease acid rains, global warming and other forms of contamination in a way.

In this regard, desire to prove the statement "Wave energy obtained from one of the unlimited motions in the world can be added to the mixture of the energy forms in Turkey" is the focus of this paper.

In Section 2, the Turkish Available Offshore Wave Power Resource will be overviewed first. In section 3, we will write about Site Selection. In Section 4, a Case Study at the Southwest of Turkey takes place. In Section 5, Conclusion is provided.

2.THE TURKISH AVAILABLE OFFSHORE WAVE POWER RESOURCE

In the TU-WAVES Project, [11] the wave climate has been studied in four regions in TURKEY;

- Black Sea Coastal sites,
- Marmara Sea Coastal sites,
- Aegean Sea Coastal sites,

- Mediterranean Sea Coastal sites.

At the end of this project, the team constructed a Wind and Wave Atlas for the Black Sea and the other Turkish Coasts with detailed statistical information on wind and wave climate in it. The values taken from the Atlas were used in potential calculations. [12]

Since knowing the first step in developing a wave energy project is to find the average resource, we have estimated the minimum power levels from monthly average wave values and the maximum power levels from average of the lowest of the maximum values and monthly average using equation (1). [13]

$$P(kW/m) = 0.49 H_s^2 T_e \quad (1)$$

Where significant wave height H_s is equal to the average of the highest one third of the waves and the zero up-crossing period T_e, which is defined as the average time between upward movements of the surface through the mean level.

Although power levels are low in general, some points can be found between 4-17 kW/m mostly at of the southwestern parts of Turkish coasts that were open to Mediterranean. (Figure 1 and Figure 2)

The intersection of two seas is the ideal location or rather; it is better to start the initial trials in the area between Izmir and Antalya to harness wave energy.

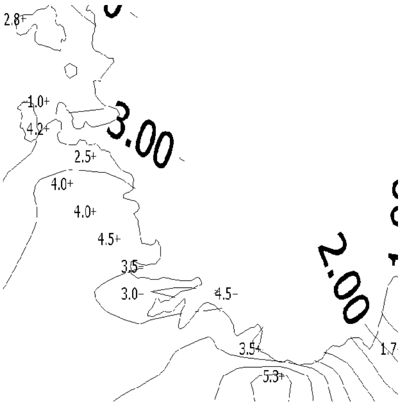


Figure 1. Minimum Wave Energy levels Available to Harness in southwest Turkish Waters

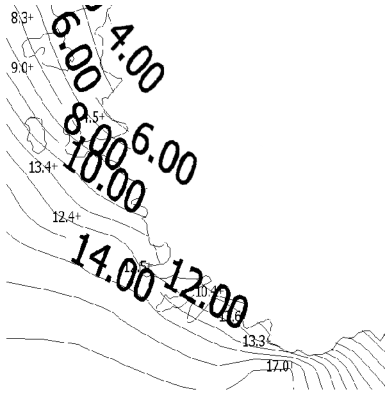


Figure 2. Maximum Wave Energy levels Available to Harness in southwest Turkish Waters

Other best sites to harness the wave energy are in the west of the Black Sea on the north of the Istanbul Straits. (Figure 3 and Figure 4)

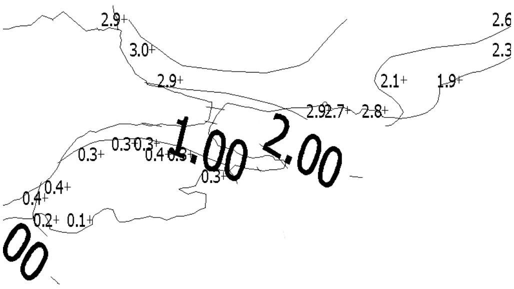


Figure 3. Minimum Wave Energy levels Available to Harness in west Black Sea

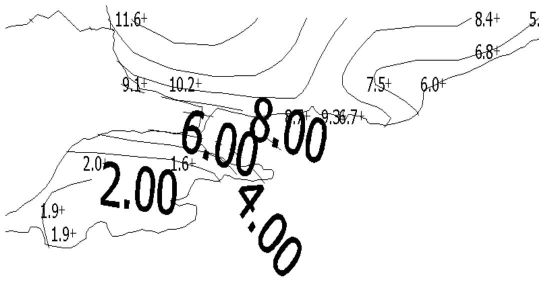


Figure 4. Maximum Wave Energy levels Available to Harness in west Black Sea

3. SITE SELECTION

Turkey has many sites with the wave potential energy resources off the Mediterranean, Black Sea and Aegean Sea coasts, which can be assumed as having sheltered waters and calm seas according to the oceans and which are also close to the network. We can focus on wave power plants consisting of a number of small wave energy converters, forming large arrays in these waters, located offshore.

The properties of a wave energy converter correspond with the climate of the sea. A perfect unit for a sea around UK may not be successful in a mild climate.

An important parameter at the beginning of a project is the wave energy development index (WEDI) value of the site. [16] This figure emerges by dividing the average annual wave energy changes by the storm wave energy changes and it is dimensionless. [14] The Figure 5,6,7 and 8 below can be used to identify some of the sites off of the Turkish coasts for more refined investigation and potential project development [15].

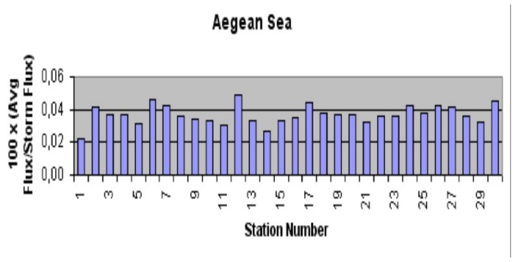


Figure 5. Wave Energy Development Index for The Aegean Sea

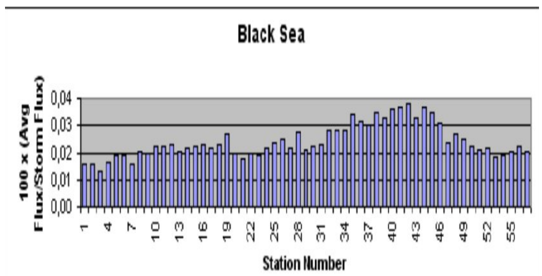


Figure 6. Wave Energy Development Index for Black Sea

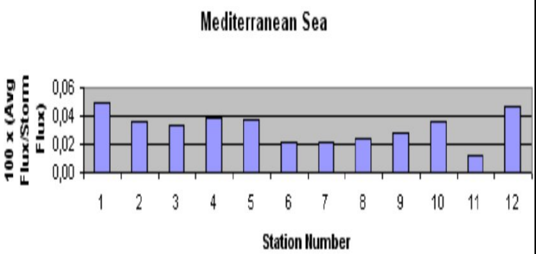


Figure 7. Wave Energy Development Index for Mediterranean Sea

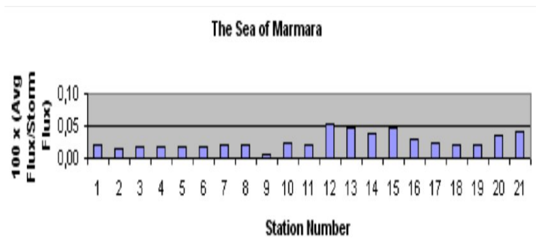
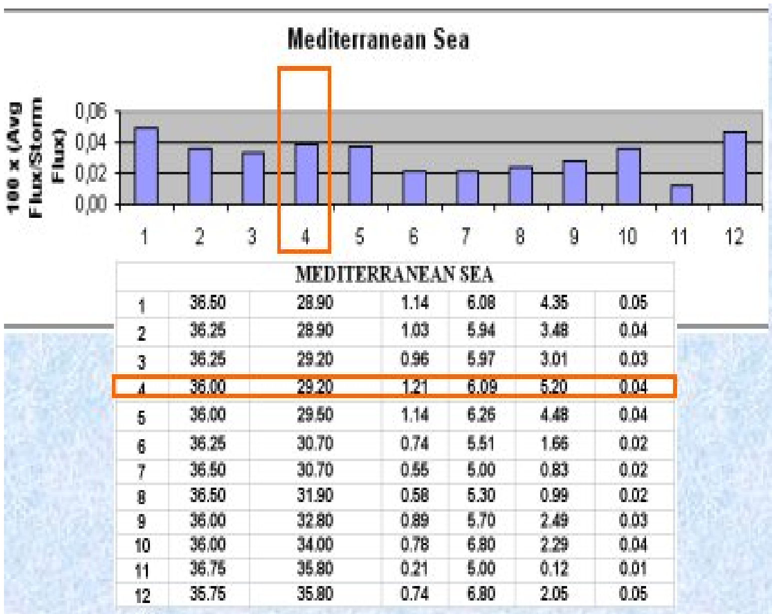


Figure 8. Wave Energy Development Index for The Sea of Marmara

The best site is selected in terms of the wave energy development index (WEDI) values and power at the site. This is because the one with higher WEDI value among the sites having the same power density will cause your design cost to be higher than the others so you have to pay more capital cost for a wave power plant to harness the annual average wave energy resource available at a particular grid point. [16] (Figure 9)



MEDITERRANEAN SEA

1	36.50	28.90	1.14	6.08	4.35	0.05
2	36.25	28.90	1.03	5.94	3.48	0.04
3	36.25	29.20	0.96	5.97	3.01	0.03
4	36.00	29.20	1.21	6.09	5.20	0.04
5	36.00	29.50	1.14	6.26	4.48	0.04
6	36.25	30.70	0.74	5.51	1.66	0.02
7	36.50	30.70	0.55	5.00	0.83	0.02
8	36.50	31.90	0.58	5.30	0.99	0.02
9	36.00	32.80	0.89	5.70	2.49	0.03
10	36.00	34.00	0.78	6.80	2.29	0.04
11	36.75	35.80	0.21	5.00	0.12	0.01
12	35.75	35.80	0.74	6.80	2.05	0.05

Figure 9. Site Selecting

The Sea State Scatter Diagram of the site, Kalkan (Mediterranean) has been prepared using the significant wave height, mean and peak wave periods, mean wave directions (more than 23000 values in one column) in an MS Excel program. (Table 1)

The diagram contains the significant Height (H) Wave Period and weighting values corresponding to H and T. Weighting values describe how many times it occurs in the time period of measurement. [1]

$$P_{ave} = \frac{\sum P_i W_i}{\sum W_i} \qquad (2)$$

Wave Height (m)	Wave Period (s)	2	2.2	2.5	2.7	3	3.6	4	4.4	4.8	5.3	6	6.4	>6,4
0.25		0	0	0	4	28	70	127	65	39	42	0	10	0
0.5		0	17	17	25	88	227	470	467	312	313	0	175	0
0.75		0	0	0	0	37	290	670	617	496	515	0	286	0
1		0	0	0	0	0	29	287	672	688	548	0	447	0
1.25		0	0	0	0	0	0	22	222	711	711	0	357	0
1.5		0	0	0	0	0	0	1	23	181	577	0	345	0
1.75		0	0	0	0	0	0	0	0	15	215	0	349	0
2		0	0	0	0	0	0	0	0	2	38	0	353	0
2.25		0	0	0	0	0	0	0	0	1	2	0	297	0
2.5		0	0	0	0	0	0	0	0	0	0	0	147	0
2.75		0	0	0	0	0	0	0	0	0	0	0	50	0
3		0	0	0	0	0	0	0	0	0	0	0	10	0
>3		0	0	0	0	0	0	0	0	0	0	0	0	0

Table 1. Sea State Scatter Diagram for Kalkan
$36^0 00'$ N, $029^0 20'$ E

One of the best sources is estimated off Kalkan, Antalya at Turkish Coastal locations from the Sea State Scatter Diagram using equation (2). Statistical analysis showed the wave power densities (between 6.6 kW/m-7.6 kW/m with regard to the range of wave heights up to 1.21 m and wave period up to 6.09 seconds were available at most of the year. (Figure 10)

WAVE POWER SOURCE					
36.00^0 N, 29.20^0 E, Kalkan, ANTALYA					
Significant Wave height (m)	Mean Wave Period (s)	Mean Wave Direction (Degree)	Peak Wave Period (s)	Power Mean (kW/m)	Power Peak (kW/m)
1,21	5,2	0,90	6,09	6,6	7,63
Wave data is obtained by using ECMWF analysis wind data though WAM					

Figure 10. Wave Power Source

Moreover, wave energy potential assessment in the site off the coast of Kalkan, Antalya has been estimated by using the theory of perturbation, equation (3). [17]

$$\overline{E} = 0.49\overline{H}_s^2\overline{T}_e\left(1 + \frac{\sigma_H\sigma_H}{\overline{H}_s^2} + 2\frac{\tau_{HT}\sigma_H\sigma_T}{\overline{H}_s\overline{T}_e} + \frac{\tau_{H^2T}\sigma_{H^2}\sigma_T}{\overline{H}_s^2\overline{T}_e}\right) \quad (3)$$

Where, $\overline{H}_s$ and $\overline{T}_e$ are the arithmetic averages and σH, σT and σH2 are the standard deviations of significant wave height, zero up-crossing period and significant wave height squared, respectively.

Regarding that all the heights and periods are dependent for a typical irregular sea, so an averaging process is used to estimate the total power as 8,7066 kW/m for this site, equation (4).

$$\overline{E} = 0.49\overline{H}_s^2\overline{T}_e\left(1 + \frac{\sigma_H\sigma_H}{\overline{H}_s^2}\right) \quad (4)$$

The latter finding for the total power has not been used in the proceeding case study. Two different values may be compared only with the results employing a prototype in a real sea.

4. A CASE STUDY AT THE SOUTHWEST OF TURKEY

In the present work, we consider a reservoir type offshore converter with the aim of comparing the previous studies made in seas having similar climates.

From this point, the low energy flux of 6.6 kW/m of Kalkan wave climate has been scaled according to the parameters of Wave Dragon test area.

The main idea for selecting Wave Dragon type of converter was that it would provide an easy and effective way to assess the turbine, generator and similar economic side impacts on the overall project by using some parameters from Retscreen, Small Hydro Project Analysis using the resemblance with overtopping wave converters. This would also provide a comparison of the results with that of the company's, which are obtained by proven and mature technology for the production of electrical energy. It is also assumed that the seawater is stored in a reservoir from where it can be poured into the turbine fans from a design head continuously. [18]

Wave Dragon designed for a 24 kW/m wave climate is supposed to be equipped with 16 low head axial turbines derived from a conventional Kaplan hydroelectric turbine. Its reservoir contains approximately 5000 m^3 water that has to be let out through the turbines in between two waves. [19]

The power density ratio is 1/3.63 between two sites. In this case study for Kalkan Antalya (3600 ^{0}N, 2920 ^{0}E), the number of the turbines is 4; so the same is scaled in the flow of water parameters as 1375 m^3.

Flow-Duration Curve Data

Time (%)	Flow (m^3/s)
0%	559,88
5%	310,17
10%	289,66
15%	267,50
20%	249,70
25%	230,12
30%	208,99
35%	189,95
40%	169,53
45%	148,96
50%	129,78
55%	109,32
60%	89,55
65%	69,31
70%	54,75
75%	44,74
80%	34,70
85%	24,56
90%	14,54
95%	7,37
100%	2,63

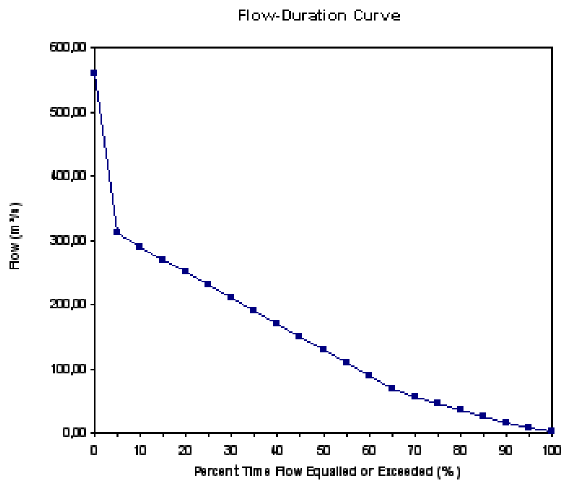


Figure 11. Flow-Duration Curve

Although the magnitudes of the extreme wave heights reached up to 8 m at the site, it was revealed that the frequency occurrence of such waves was not satisfactory throughout the year. Proportional to the calculated Power data and corresponding statistical Wave Periods (again using excel program), the flow-duration of the sea water is pumped from the convector is specified by twenty-one values Q0, Q5,..,Q100 representing the flow-duration curve in 5 % increments. In other words Qn represents the pumped sea water flow that is equaled or exceeded n % time of the time. With this curve we find the firm flow is equal to 7.37 m^3/s (Figure 11) to supply water to the turbines continuously with 95% of the year.

The optimum gross head value has been found as 10 m where the greatest gain comes. This value is the drop in elevation at the site and is used to calculate the potential power output at the site.

The model calculates the firm flow that will be available for electricity production based on the flow-duration curve data; the percentage of time the firm flows should be available. The firm flow is often defined as the flow available at least 95% of the time.

The degree of sophistication used to describe the load depends on the type of electricity grid considered. In this Case Study, it is assumed that the daily load demand is the same for all days of the year and can be represented by a load-duration curve. Peak load is taken as 1000 kW. Energy demand outcomes annually 5225 MWh and daily 14.3 MWh (Figure 12)

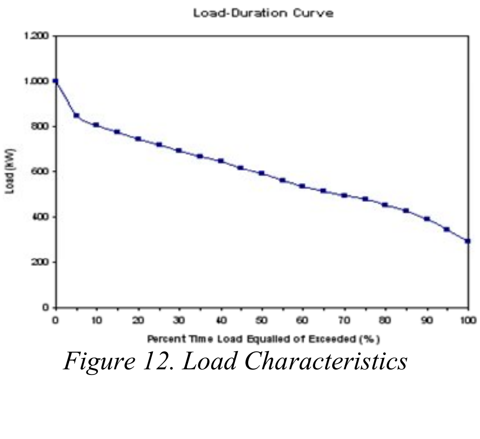


Figure 12. Load Characteristics

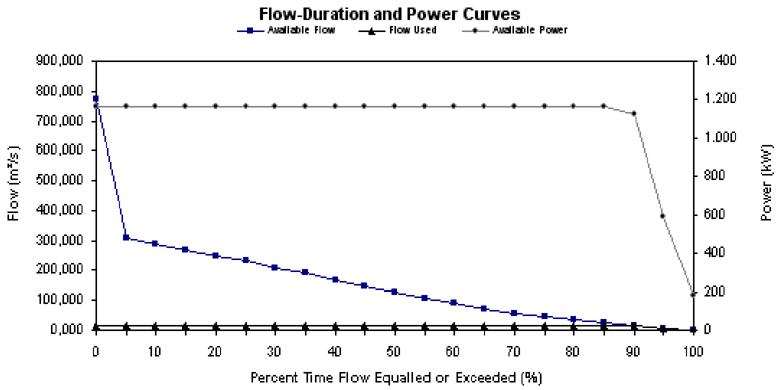


Figure 13. Annual Energy Production

This Wave Energy Project Model calculates the estimated renewable energy delivered (MWh) based on the flow-duration curve, the design flow, and the load-duration curve for each of the flow-duration curve values. (Figure 13)

Paying attention to the plant characteristics and wave climate over the sea site and the rated flow that could be provided from the reservoir, it can be calculated that the each over all turbine efficiency as 91, 90.6 % respectively at design flow. (Figure 14, 15)

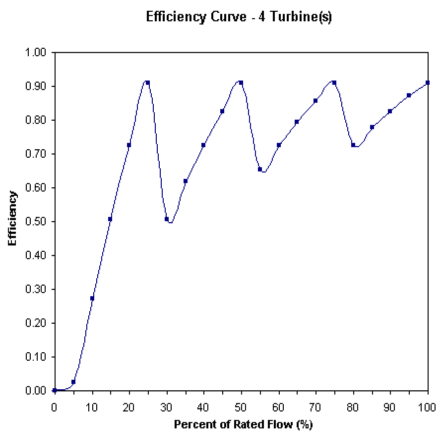


Figure 14. Efficiency of Propeller type of Turbine

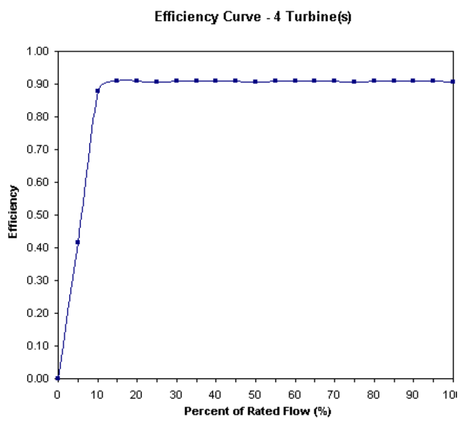


Figure 15. Efficiency of Kaplan type of Turbine

With the average wave height of 1.21 m and a wave reservoir of 1375 m^3 of water and up to 6.09 s of wave period, if it is assumed it is all available power, one system can harness about 9.368 GWh annually from the sea waves. The total initial costs have been estimated by converting from the small hydro such as subtracting the land costs and adding the carrying costs.

The total initial costs are the sum of the estimated feasibility study, development, engineering, energy equipment, balance of plant and miscellaneous costs and are the inputs of this calculation.

5. CONCLUSION

Wave energy converter technology is still at the R&D phase. Without the subsidies, the electricity production cost still is not as low as the cost of electricity produced by thermal fuels. New technologies still can be developed to add wave energy to the other sources of energy in Turkey.

In light of the findings from exploring in the wave energy literature of the world, the Baltic Sea and devices designed for that sea can be a sample for the studies in Turkey.

- To harness wave energy in small seas requires;

- To use some converters as wave energy breakwaters only at the ports in the near shore.

- Small-scale converters to be convenient for protecting some of the coastal structures or the highway all along the Black Sea cost, planned to be constructed and for meeting some portion of the local or remote electricity need at the shoreline.

- Development of the devices requires more in the offshore.

The devices for the low wave climates are still being developed. It is not too late to join these projects or start new designs.

The regions in the west of the Black Sea in the north of Istanbul Straits and off the southwestern and western coasts of Aegean Region have been suggested as the best sites to harness the wave energy. If we leave out possible areas for shipping lanes, regions for submarine training, etc., and if we ignore most of the sites on the eastern and southern Anatolia coasts, where the wave power levels are low for commercial exploitation, wave farms that can be set up at three main regions off the coasts of Turkey can harness totally about 10 TWh/year with an annual wave power between 3 and 17 kW/m. This is 7.8% of the economically feasible potential of current Turkish hydroelectrical energy. This can be more than this value when progressing technologies are considered being used in the wave farms.

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