

REVIEW

A Review of Tidal and Wave Energy in Southern Waters of Iran

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ARTICLE INFO

Article history

Received: 19 March 2020

Accepted: 9 April 2020

Published Online: 31 October 2020

Keywords:

Tidal Energy

Iranian waters

Sustainable

Greenhouse effect

Policy-makers

ABSTRACT

This paper discussed the historical review and current status of tidal current energy, problems, and challenges in this energy commercialization. Fossil fuels are nonreplicable and also have negative greenhouse effects on the environment, so the world needs new and sustainable energy resources such as the ocean, wind, solar, biofuels, etc. This review paper focused on the initiative tidal current energy technology and efforts in the development of such energy to extract power from. Iran's southern waters have been selected in this review. Some former projects and studies, current status, and impact of the tidal current and wave energy on the environment and aquatic life are discussed. Also, the limitations, challenges, and problems in the way of using this energy and infrastructure to transfer the generated power such as grid connections are proposed. It is decided that Chabahar, Bushehr, and Khowr-Moussa are the best locations for harnessing tides and wave energy. This study is among the first review of works done in the aspect of the tidal current energy in Iran and the results will help the investors, policymakers, companies, and researchers to have access to a comprehensive list of up-to-date studies and statistics to better understand the current situation to secure the projects in this field.

1. Introduction

Today, there are extensive efforts in solving energy crises the world encounters. Different industrial, academic, and commercial communities work significantly towards this issue. The common point in all activities is finding new energy resources to replace the current exhaustible fossil fuels which are very harmful due to the negative effects on the environment. Renewable energies including tidal currents are promising resources. More than seventy percent of the world is covered with water, and there is a huge hidden energy potential that can be extracted from in different forms

such as tidal, thermal, waves, and currents. This study focused on tidal and wave energy. To accurately characterize an optimum site, assessing available resources and their potentials as a pre-requisite is required. The costs of bringing wave energy ashore and the benefits of harnessed energy should have economic justification. This article is among the first review of available tidal and waves energy resource estimates for Iranian waters. There is an increasing concern on global warming so it forced different communities such as policymakers to adopt decisions and apply methods to reduce it. One of these contraptions is generating green electricity. Tides

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are one of the best resources as they are forecastable and make it less challenging to be incorporated into the electricity system. Gravitational and centrifugal forces between Earth and Moon cause tides. The tidal waves are the results of rhythmic rising and lowering of water surface. There is a proven success in using tidal energy. Different methods in harvesting this energy can be tidal currents, waves and turbines and tidal barrages which work with the fall and rise of the sea level. Narrow channels and coastal areas experience tides. There are two types of tidal currents; flood current -in the direction of coasts, and ebb currents which recede from the coasts.

2. Literature Review

Table 1 shows the most recent previous works done in this field. However, compared to the numerical modeling more statistical works have been done in wave and tidal energy analysis.

Table 1. previous studies on the wave and tidal energies

Reference	Year	Study	Model	Location	Focus
Saket-Shahidi	2011	Wave	SWAN	PG	WECs, best site
Gorji	2013	Tide	Statistic	PG	Tide capacity, turbines, ranking hotspots
Mardani-Zare	2014	Wave	Statistic	Chabahar	Energy utilization, exploitation technology
Akhyani	2014	Tide, current	GETM	PG, Oman Sea	Tidal energy in the upper water
Kamranzad	2016	Wave	SWAN	Oman Sea	The temporal and spatial model
Khojasteh	2017	Renewable energy	Statistic	Iranian waters	Different renewable energy
Zanous	2018	Wave	Statistic	South of Iran islands	WECs

3. Region of Study

There is a growing energy demand due to population growth. Also, because of economic development and abundant and cheap energy, consumption is very high in Iran. Due to the country reliance on oil and gas, despite its substantial potential, renewable energy is a new concept in Iran. The country recently started to develop and apply the renewable energies- tidal energy is even more new concept. Iran's unique geographical position in addition to being surrounded by water bodies in both north and south parts makes it economically feasible to use tidal energy^[1]. This review focused on the southern waters of Iran as there are long coastlines and high potential due to the con-

nection to the free waters.

4. Materials

The research has been conducted based on the analysis of the previous works, regulations, the subject's literature and information from websites. The basis for the selection of the analysis method has been the type of gathered information.

5. Results and Discussion

Tidal and Wave Energy Potential in Iran

In 2011 Saket and Shahidi considered north of the Gulf of Oman to investigate the wave energy potential. They applied the SWAN numerical model to simulate the wave parameters. Results were compared to ADCP data and buoy. The runtime period was set for 23 years from 1985 to 2007. As other research concluded, Chabahar Port determined to be the best site for wave power. As expected, monsoon season (from June to August) in the southeast of the Indian Ocean produced the most energetic waves. It is estimated that the deep-waters in the world have the potential of 1 to 10 TW of wave energy. There can be both offshore and nearshore wave farms by installing different types of WECs. They selected four stations in their study (Figure 1) and calculated the annual wave energy from the significant wave height and period which was estimated to be 2.8 kW/m in an average year. Despite estimated low wave energy, but due to the remarkable wave power, the best location for extracting energy was determined to be Chabahar Port with the most energetic waves from June to August^[2].

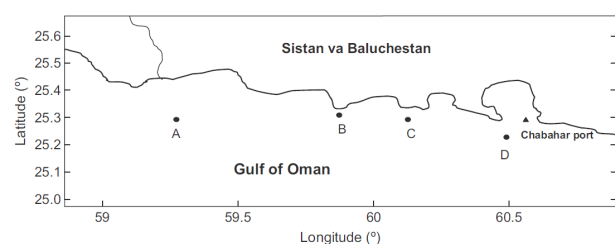


Figure 1. The location of sites A to D along the Gulf of Oman^[2]

Shahidi et al., in 2011 have estimated the wave energy in the Persian Gulf. Using SWAN numerical model, they modeled the wave for 25 years. Input data were obtained from ECMWF. They demonstrated that the middle of the Persian Gulf has higher averaged wave power (Figure 2). And the main reason is the long coastline and fetch of the Persian Gulf in NW-SE direction which is the dominant wind direction. Assalouyeh was determined as the best site^[8].

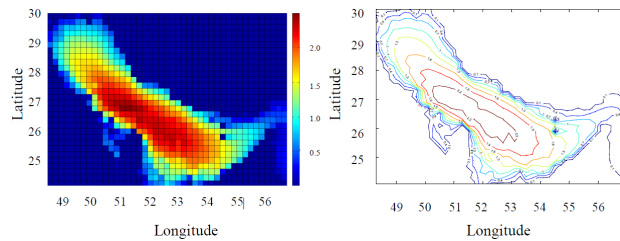


Figure 2. Wave power (m^2s) distribution and contour plot in the Persian Gulf^[2]

Some locations such as Chabahar has abundant tidal current resources. Many permanent tidal stations in Southern Waters are established by National Cartographic Centre (NCC). Tide gauges installed in the Persian Gulf and Oman Sea are demonstrated in figure 3. Teiss Port, Ab-Shirinkon and Kenarak Port are located in Chabahar Bay. Electricity is generated from the kinetic energy of tidal current by helical turbines. Another tidal application in Chabahar Bay is developing a fishery industry using the Mashta method. So far, there is about 260 MW of installed capacity in tidal energy in Iran. In respect of costs, despite there are some disadvantages in tidal energy projects such as bigger investment, long construction period and longer payback periods compare to other types of renewable energies, however, once the project is finished it only needs lower maintenance and running costs and the lifetime is thirty years. Also, the tidal plants can work for an indefinite time. Converting tidal energy to electricity applies to similar technology in hydroelectric power plants. Single-pool ebb tide system is the most economical scheme in Iran^[1].

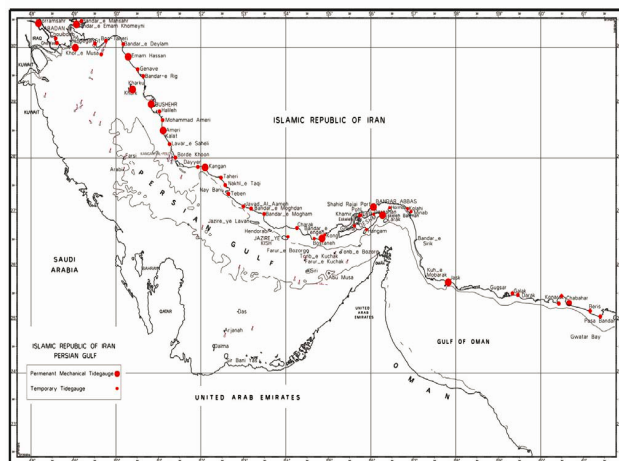


Figure 3. Map of Iranian tide gauge network^[1]

Table 2 illustrates the tidal power in W/m^2 for six selected sites. According to this table, the best ranks are for Bandar- Abbas Port, Chabahar Port, and Khowr-Moussa, respectively.

Table 2. Tidal power values (per m^2) for 6 selected locations of the south coast of Iran^[1]

Location of the south coast of Iran	Tidal Power (W/m^2)
Khor-Moussa Estuary	1.1
Bushehr	0.38
Kangan	1.1
Bandar-Abbass	2.35
Jask	0.82
Chabahar	1.93

Madani and Zare, in 2014 worked on the utilization of sea wave energy in Chabahar. Wave energy potential for 14 coastal cities in the north and south of Iran was calculated and is shown in table 3. Chabahar with 5.8 kW/m, having 265 m shoreline and total generating power of 1539 MW was selected as the best location to construct the wave power plant Lenj and Bushehr followed Chabahar with 1222 and 1045 MW, respectively. The power capacity for all 14 cities was totaled 6540 MW. Monthly and annual wave power for Chabahar is shown in table 4^[3]. August, February, and July respectively recorded the highest values of 20.61, 18.30 and 18.17 MW, while December demonstrated the lowest measure of 2.08 MW.

Table 3. Wave power in different cities in Iran^[3]

Location	Power/meter (kw/m)	Shoreline (km)	Power (MW)
Abadan	2.9	34	101
Abu-Moussa	5.1	5	26
Anzali	3.4	124	423
Astara	0.6	83	50
Babolsar	2.2	155	341
Bandar-Abbass	0.9	232	210
Lenj	3.4	359	1222
Bushehr	2.2	474	1045
Chabahar	5.8	265	1539
Jask	3.2	289	925
Mahshahr	1.7	223	380
Noshahr	1.1	99	110
Ramsar	1.4	100	141
Siri	5.3	5	27
			Total: 6540

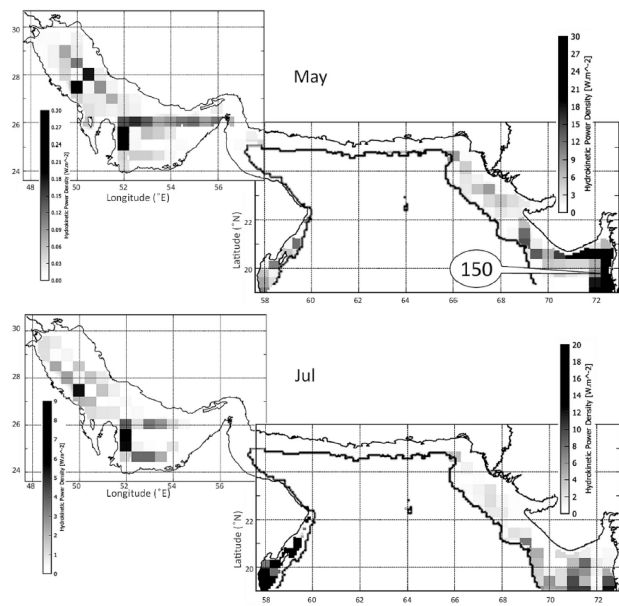
Table 4. Monthly and annual wave power ^[3]

Month	Wave power (MW) -all wind directions
January	11.19
February	18.30
March	12.88
April	9.55
May	9.41
June	14.35
July	18.17
August	20.61
September	10.74
October	6.08
November	7.86
December	2.08
Year	12.60

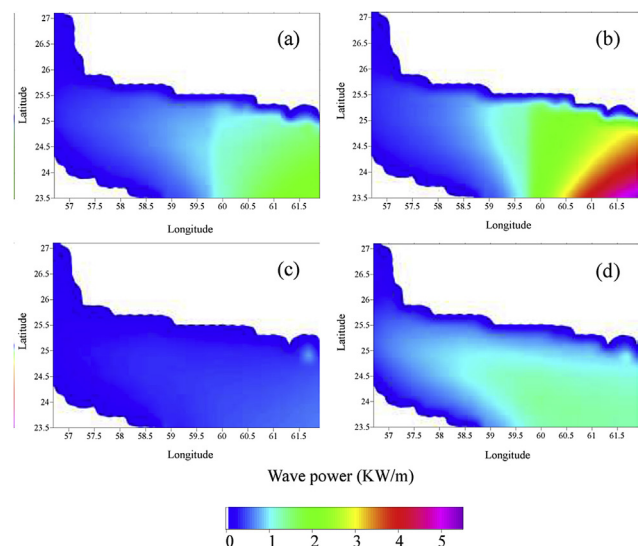
They discussed the wave energy technology such as Oscillating Water Column (OWC) -fixing to the seabed or sea rocks. Wave Overflow Device/Generator -storing water above the free sea-surface and using a hydraulic turbine to convert the energy. Also, mentioned the wave numerical modeling of Iranian running by the Iranian Port and shipping Organization. They simulated 12-year wave energy patterns and values with Mike 21 SW numerical software using ECMWF data (from 1992 to 2003) ^[3].

Akhyani et al. used a numerical model in 2014 to appraise the current power in the southern waters of Iran. There is about 2000 km tidal coastline in Iran. A 3-D simulation is done on the circulation of the Persian Gulf and the Gulf of Oman to access the power density of ocean currents. Results showed current energy around 50 m from the surface increases from late winter to early spring and again in late summer to early autumn which is the Monsoon season. Tides can generate 3.5 TW ocean current kinetic energy and this value is 3.1 TW by wind (Ekman transport). So these two types of energy are the main energy resources in Ocean. General Estuarine Transport Model (GETM) used to stimulate circulation. To calibrate and verify the model Intergovernmental Oceanographic Committee (IOC) was used and wind data obtained from ECMWF. Based on the results, the maximum and average current velocity were 1.1 and 0.5 m/s. However, in the time of this study, there was no commercial equipment to harvest current energy less than 1 m/s. Also, the generated results were applicable to waters deeper than 1000 m. The results confirmed that the maximum power density takes place in summer (the Monsoon season) when the winds are stronger. May and July with a max power range of 30 and 9 W/m² demonstrated the highest hydrokinetic power density in the Persian Gulf, (Figure 4a and b). The reason is that the Persian Gulf is not

directly affected by monsoon and there is a time delay ^[4].

**Figure 4.** The power density of currents for a) May, b) July ^[4]

Spatial distribution of wave power in ports of Bushehr and Assalouyeh investigated by Kamranzad et al. in 2016. A wave model (SWAN) was applied to assess the wave energy potential in the north part of the Gulf of Oman (Figure 5), by selecting five stations- Sirik, Jask, Googsar, Chabahar, and Govatr, numbered 1 to 5, respectively. The wave power showed the highest value in summer particularly in the mouth of the Indian Ocean. Monthly distribution for mean, max, and the ratio of max/mean wave power are illustrated in figure 6 ^[5].

**Figure 5.** Wave power (kW/m) distribution in the Gulf of Oman in (a) Spring, (b) Summer, (c) Autumn and (d) Winter ^[5]

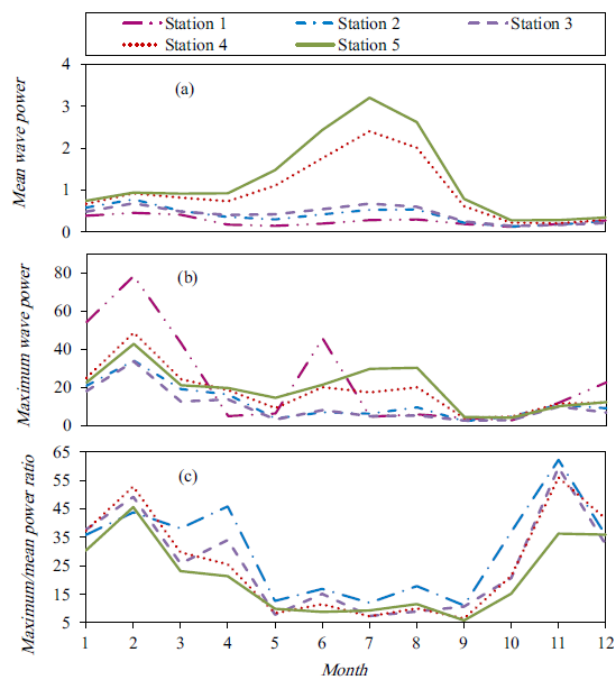


Figure 6. Monthly distributions for (a) mean, (b) maximum and (c) ratio of max/mean wave power (kW/m)^[5]

Wind reanalyzed data obtained from the European Center for Medium-range Weather Forecasts (ECMWF) from 1992 to 2002. Bathymetric file obtained from NOAA's National Geophysical Data Center (NGDC). To validate the model, they compared the results with observed wave records in a buoy located in Chabahar at 17 m water depth. Table 5 reveals the exploitable storage of wave energy in kWh/m per unit in five stations. They found that wave power increases from Strait of Hormuz towards the Indian Ocean, with the maximum value in summer and minimum in winter. Station 5 has the highest mean wave power. The reason is the summer monsoon, occurring in the east of the Gulf of Oman. The best suitable and not-suitable stations are 5 and 1, respectively. In the eastern Gulf of Oman, the total and exploitable storage of wave energy is estimated at 11000 and 2000 kWh/m, respectively^[5].

Table 5. Total and exploitable storage of wave energy (kWh/m) per unit^[5]

Station No.	1	2	3	4	5
T_e	37.06	249.09	247.18	1266.69	1658.31
E_t	1217.39	3546.63	3768.52	8778.68	11170.04
E_e	5.15	10085	106.34	1269.39	2114.54

By 2017, at least ten sites of ebb and flow were recognized and five of them show promising potential for generating electricity. Khor-Moussa is the best among them followed by Pol and Kaveh and Imam Khomeini Ports. Having at least two rises and falls per day, Imam Khomeini has the potential capability of producing 60 to 80 MW of tidal energy while it benefits from the local purchasers such as petrochemical industries, maritime ports, and coastal cities. Although the technology required to harvest tidal energy is well developed, it is still expensive. The main barriers are construction costs and period (around 10 years). Having a natural spiral form, Khowr-Moussa -located in the southern Bushehr province -has the characteristic to store water at spring tides and return it at neap tides. Another suitable site is Khouuran Strait benefiting from fast currents. While there is more than 2000 km coastline on the south of Iran along the Persian Gulf and the Gulf of Oman, and more than 650 km in the north side along the Caspian Sea, but renewable energy shares less than 1 percent of the total energy production by 2013. Based on the predictions, world marine energy capacity will be 17 GW with an output of 60 TWh by 2035. The average wave energy in the Persian Gulf is about 6.1 kW/m, while the minimum and maximum potentials are 16.6 and 19 kW/m, respectively. In the Gulf of Oman, the average value reaches 12.6 kW/m. The best-exploiting regions are Chabahar Port, Bushehr, Assalouyeh and Khowr-Moussa. For tidal energy, Khowr-Moussa with an average value of 15.8 MW is the best spot follows by Hengam Island and Greater Tunb^[6].

In 2018, Zanous et al. did a feasibility study on the south islands of Iran to harness wave energy, (Figure 7). Using 10-year ECMWF data, they investigated the potential of wave energy. The results showed that in Chabahar Port the wave energy reaches a maximum value of 17 kWh/m in summer while a peak of 10 kW/m in Kish Island (located on the Persian Gulf and the Strait of Hormuz) occurs in winter. They determined the Chabahar Port with significant wave height and energy flux, Kangan Port, Kish Island, and Kharg Island as the best wave energy hotspots with the total amount of 88.75, 35.78, 25 and 22 MWh/(m.year). From their findings, the Persian Gulf in winter and the Gulf of Oman in summer have high potential in exploiting this type of energy. Generally, the height, energy flux and period of waves in the Gulf of Oman are more than the Persian Gulf. The main reason is that the Gulf of Oman is connected to the ocean. Table 6 summarized the ranking in the selected sites^[7].

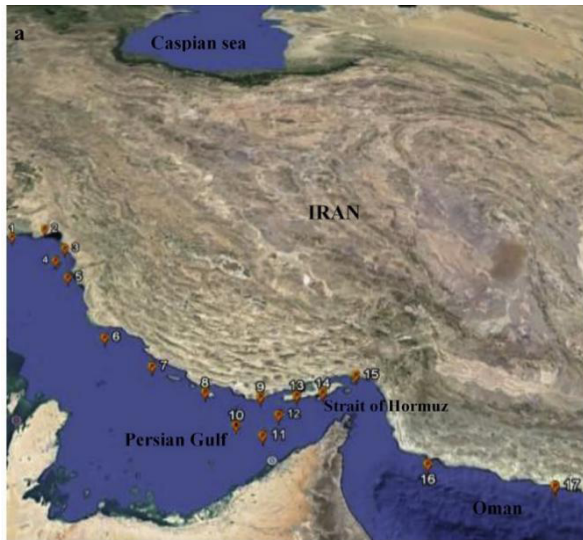


Figure 7. Study region for tidal and wave energy^[7]

Table 6. The wave significant height and period range with the maximum annual energy and annual percentage of occurrence of sea states^[7].

Size	Orderreferences	H(M) T(S)	Wave Energy (Mwh/M)	The Probability Of Occurrence In Year (%)
Khark Island	First	4-5	5.8	24
	Second	0-2 5-6	4	5
Kish Island	First	1-2 5-6	5	8
		1-2		
Gheshm Island	First	4-5	2.2	4
	Second	0-1 5-6		
Chabahar Port	First	1-2 9.5-10 8-8.5	17	15
Kangan Port	Second	1-2	12	10
	First	5-6 1-2 4-5	8.8	9
Lenge Port	Second	1-2	8.8	9
	First	5-6 1-2	6 3	11 6

The summary of the numerical modeling on the wave energy in the southern waters of Iran is shown in table 7.

Table 7. Summary details listed for numerical wave models and hindcast data used to estimate wave and tidal energy resources in Iranian southern waters

Reference	Kamranzad et al., 2016	Akhyani et al., 2014	Saket & Shahidi, 2011
Model	SWAN	GETM	SWAN
Period	1992-2002	1992-2008	1985-2007
Grid Resolution	0.2°	0.1°	0.0333°
Model Size	56.9-61.5 N 24.9-26.3 E	19-31.5 N 47.5-73.5 E	59-61.6 N 25-25.45 E

Model Input	Wave	Tide (1h), Wind (6h)	Wave-Wind
Data Source	ECMWF	ECMWF, Quick Scat Satellite	Iran Meteorological Organization (IRIMO)
Data Temporal Resolution	6-h	6-h	3-h
Data Spatial Resolution	0.5°	0.5°	0.5°
Temporal Resolu- tion	3-h	-	3-h
Bathymetry	NOAA (1min)	INCO	INCO

6. Conclusion

Compare to the other types of energy, tidal energy is less sustainable but there is fast-rate progress in using this type of energy mainly due to aspects such as ecological and economic feasibility. Considerable potential exists to develop marine energies such as wave and tidal in Iran. From the historical research and former investigations, In the Persian Gulf with 6.1 kW/m, average wave energy Chabahar Port with 265 m shoreline and 5.8 kW/m wave energy and total power generation of about 1540 MW and Khowr-Moussa (about 16 MW tidal energy) are suggestive of substantial wave energy resources to install wave farms and during Monsoon months shown the highest energy potential. Also, Imam Khomeini Port has a capacity of 60-80 MW of tidal energy and is one of the promising sites. Iran with very long coastlines in both north and south of the country has a significant potential for harnessing marine energies such as tide, wave, and wind. In addition to creating many jobs, reducing global warming gas emissions Iran advantages from being surrounded by neighbors such as Pakistan, Iraq, Afghanistan, and Turkey who have a very high demand for energy and are willing to buy energy and provide it from Iran. So, it can simply export the extra generated green energy to the neighbors. Due to the economic crisis in Iran, offshore Wave Energy Converters (WECs) are not justifiable financially. There are high costs, difficulties in manufacturing, transmission, and maintenance in offshore devices. Instead, nearshore devices are more applicable. Examples of nearshore devices are Small Bottom-referenced Heaving Buoy (SBHB), and Bottom-referenced Submerged Heaving Buoy (BSHB). Shoreline WECs are among the easiest installed and maintenance equipment and have the advantage of working even in shallow waters so do not need deep water mooring and long underwater electric cables. The most applicable tidal system in Iran is Single-pool ebb tide. Transforming wave energy technologies is still in the development stage. Applicable type of WECs is determined by the wave characteristics such as wave height and period range. Applying the traditional method

in obtaining tidal energy first achieved by Germany and then many countries were attracted to. There is a need for a complete and applicable study and research in Iran on this subject. There are very few numerical modeling works have been done on tidal and wave energy. Generally, statistical and field measurement works are much more available than numerical simulation. Numerical modeling helps significantly to understand the behavior and potential of this marine energy without imposing high costs like field measurements. Also, it can evaluate arbitrary domain and resolution unlike the field works, so to attain appropriate measures to determine the productivity of tidal and wave energy improvement in this technology like the higher spatial resolution is a must.

References

- [1] Gorji-Bandpy, Mofid & Azimi, Mohammadreza & Jouya, Mohsen. Tidal Energy and Main Resources in the Persian Gulf. *Distributed Generation & Alternative Energy Journal*, 2013, 28: 61-77.
DOI: 10.1080/21563306.2013.10677551
- [2] Saket, Arvin, Etemad-Shahidi, A. Wave energy potential along the northern coasts of the Gulf of Oman, Iran. *Renewable Energy*. *Renewable Energy*, 2012, 40: 90-7.
DOI: 10.1016/j.renene.2011.09.024
- [3] Mardani, Ramin. Study On Wave Energy in Chababhar, Iran. Conference paper ISME. 22nd International Conference on Mechanical Engineering, Iran, 2014.
- [4] Akhyani, Mahmood, Chegini, Vahid & Bidokhti, A.A. An appraisal of the power density of current profile in the Persian Gulf and the Gulf of Oman using numerical simulation. *Renewable Energy*, 2015, 74: 307-317.
DOI: 10.1016/j.renene.2014.08.015
- [5] Kamranzad, Bahareh & Chegini, Vahid, Etemad-Shahidi, A. Temporal-spatial variation of wave energy and nearshore hotspots in the Gulf of Oman based on locally generated wind waves. *Renewable Energy*, 2016, 94: 341-352.
DOI: 10.1016/j.renene.2016.03.084
- [6] Khojasteh, Danial, Khojasteh, Davood, Kamali, R., Beyene, Asfaw, Iglesias, Gregorio. Assessment of renewable energy resources in Iran; with a focus on wave and tidal energy. *Renewable and Sustainable Energy Reviews*, 2017, 81.
DOI: 10.1016/j.rser.2017.06.110
- [7] Pasha Zanous, Sina, Shafaghat, Rouzbeh, Alamian, Rezvan, Shadloo, M. S., Khosravi, Mohammad. Feasibility study of wave energy harvesting along the southern coast and islands of Iran. *Renewable Energy*, 2018, 135.
DOI: 10.1016/j.renene.2018.12.027
- [8] Etemad-Shahidi, A., Kamranzad, Bahareh. Wave energy estimation in the Persian Gulf, 2011. DOI: 10.13140/RG.2.1.1089.6805