Challenges of Marine Power in the Balkan Region

D. Dzhonova-Atanasova, R. Popov, A. Georgiev

Abstract—**The world power generation is in a process of transition from fossil fuels to renewable and sustainable power sources. The part of the electricity from alternative energy technologies is growing rapidly. New engineering approaches and devices are continuously created by the researchers in the field of power engineering, aimed at obtaining energy with less harm for the environment and the life on the planet. The present work is an initial evaluation of the possibilities for marine energy conversion in the Balkan region. The focus is on energy from the sea including energy from waves, currents, salinity, temperature difference etc. The main purpose of the work is on the basis of assessment of the power potential determined by the geographical characteristics of the seas in the region and the scientific, technological and economical level to make some conclusions about the prospects in this area.**

Index Terms— **assessment, energy conversion, energy resources, marine power, power potential, wave energy.**

I. Introduction

THE FOSSIL fuel dependent production of energy leads to continuously deepening ecological problems. The scientists and engineers in the field directed their efforts towards energy efficient technologies, decreasing the pollution caused by fuel combustion, as well as inexhaustible and sustainable energy resources like sun, wind and ocean. The share of the energy from renewable sources is rapidly growing, Fig. 1. Despite of the crises of the late years, the renewable electricity cost decreases, due to the growing awareness of the authorities that the transition to sustainable power production is the only way for future development of the mankind. The European Council in 2007 adopted ambitious energy and climate change objectives for 2020 [1] – to reduce greenhouse gas emissions by 20%, to increase the share of renewable energy to 20%, and to make a 20% improvement in energy efficiency.

Compared to 2011, the structure of electricity production in 2012 in EU-27, Fig. 2, taken from [3], is as follows:

- the production of conventional thermal electricity decreased by 4.6 % and accounted for 52.3 % of total production;
- the production of electricity by nuclear power plants decreased by 2.7 % and accounted for 27.1 % of the total;
- the electricity production by hydropower increased by 9 %, while the production by wind increased by 11.5 % and represented respectively 11.7 % and 6.4 % of the total.

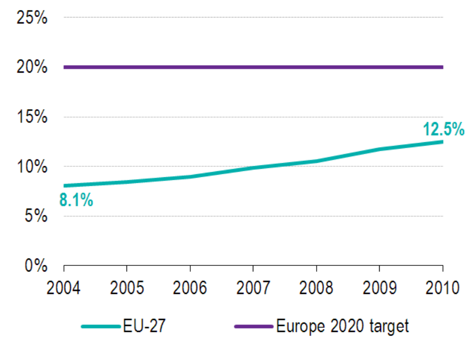


Fig. 1 EU 27 Share of electricity production by renewable sources in gross production, source [2]

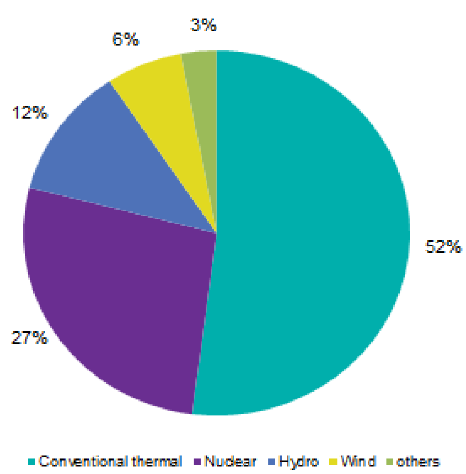


Fig. 2. EU 27 electricity production by source, 2012 (in %), source [3].

II. Marine Renewable Resources

The ocean contains great amount of energy, but its conversion to useful form like electricity requires advanced technology that is still under development. The main types of ocean energy technologies are wave energy, tidal energy, temperature gradient energy and salinity gradient energy. The ocean energy comes from the sun, which heats the atmosphere

D. Dzhonova-Atanasova is with the Institute of Chemical Engineering at the Bulgarian Academy of Sciences, “Acad. G. Bonchev“ Str., Bl 103, Sofia 1113, Bulgaria (e-mail: dzhonova@bas.bg, dzhonova@mail.bg).

R. Popov is with the Department of Optoelectronics and Laser Engineering, Technical University of Sofia, Branch Plovdiv, Bulgaria (e-mail: rum_pop@yahoo.com).

A. Georgiev is with the Department of Mechanics, Technical University of Sofia, Branch Plovdiv, Bulgaria (e-mail: AGeorgiev@gmx.de).

and the ocean water, and thus generates wind and ocean currents. Prospects for the various marine energy sources including their power potential and energy density were assessed after the 1973 energy crisis, Table I from [4].

TABLE I
MARINE RENEWABLE RESOURCES, [4]

Resource	Power potential (TW)	Energy Density (equivalent to meters of hydraulic head)
Ocean Currents	0.05	0.05
Ocean Waves	2.7	1.5
Tides	0.03	10
Thermal Gradient	2.0	210
Salinity Gradient	2.6	240

The comparison of the characteristics of the ocean resources to other renewable resources in Table II, from [5], shows that the marine power density is the highest but at the highest energy cost, the technologies are under development and much research and new approaches are needed.

A. Tidal energy

The tides are created from the Earth-Sun–Moon gravitational interaction. The most practical use for tidal energy is for conversion to electricity. The tide conversion technologies are two main types: using tidal range and tidal currents. The tidal range is used by creating a dam, similar to hydroelectric dams, or barrage containing several gates and turbines, across an estuary. Since the first tidal barrage in La-Rance estuary in France built in 1962 and still in operation, lot of engineering solutions and devices for tidal range and current power have been proposed [6, 7].

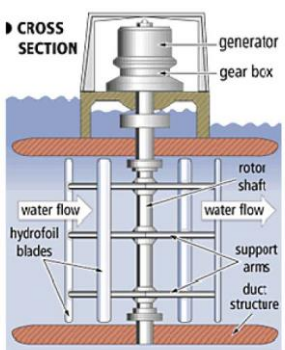


Fig. 3. Vertical Axis Hydro Turbine, Blue Energy Canada Inc., (on the basis of the wind turbine of Darrieus, 1931), source [9].

The current power is more promising than the tide range in the seas around the Balkan Peninsula, where the tides are very limited. Some examples of commercial current energy converters are given in Figs. 3 to 5. Currents are also generated by temperature, pressure, water salinity difference and wind. The ideal locations for tidal current power generation are basins with a relatively narrow entrance, such as areas between islands, narrow straits, and headlands and Aegean islands offer this morphology [5].

Fig. 4. Horizontal Axis Hydro Turbine tested at the University of New Hampshire, source [10].

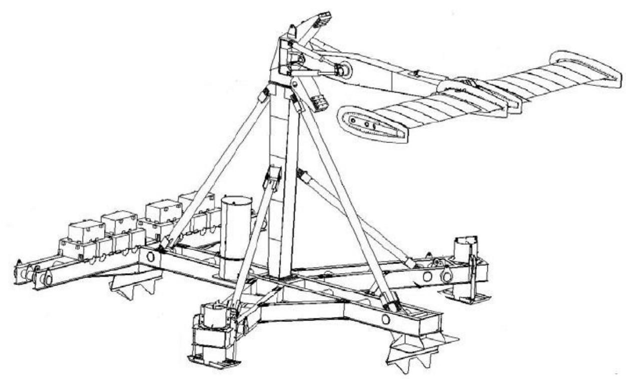


Fig. 5. Oscillating hydrofoil, Stingray Assembly © Engineering Business Ltd 2005, source [11].

The expression for estimation of the power of the current, i.e. the kinetic energy passing per unit time of the column of fluid upstream of turbine, [8], is

$$P_o = \tfrac{1}{2}(\rho A_1 u_o) u_o^2 = \tfrac{1}{2}\rho A_1 u_o^3, \qquad (1)$$

where ρ=1025 kg/m^3 -density of the sea water, A_1- cross-sectional area of the turbine disc, m^2, u_o- tide current speed, m/s.

TABLE II
RENEWABLE ENERGY RESOURCES, [5].

	Solar	Wind	Wave	Tidal/ Current
Development Status	Early Commercial	Mature Commercial	Early Commercial	Early Commercial
Source	Sun	Uneven solar heating	Sun-wind	Gravity of moon & sun
Annual Average Power Density	0.175 -0,2 kW/m^2 (fixed tilt at latitude Winnipeg - Calgary - Edmonton	0.6 - 1kW/m^2 (Rocky Mountains, offshore BC)	30 - 45 kW/m (Pacific Coast) 10 - 25 kW/m (Atlantic Coast	4-9 kW/m^2 (Minas Basin) 0.5 - 2 kW/m^2 (other sites)
Intermittency	Day-night; clouds, haze, and humidity	Atmospheric fronts and storms (local winds only)	Sea (local winds) and swell (from distant storms)	Diurnal cycles
Energy Cost	9 c/kWh (Photovoltaic)	4 c/kWh (Wind turbine 6-9 m/s wind spd.)	~ 10 c/kWh	~10 c/kWh

When assuming 40% efficiency of tidal current power to electricity the following relation is obtained:

$$q \approx 0.1\rho u_o^3 . \quad (2)$$

The SeaGen 1.2 MW device, [12], of horizontal axis type was the world's first grid connected commercial scale tidal current device and has continued to lead the way in tidal stream technology. Since installation in 2008 at Strangford Lough, Northern Ireland, SeaGen has generated over 8 GWh of electricity.

B. Ocean thermal energy conversion (OTEC)

Ocean thermal energy conversion (OTEC) allows production of electricity using cold water from the deep seawater (1000 m and 5◦C) and surface water (between 25 and 28◦C) as hot spring. With this temperature gradient, typical for the tropical and equatorial seas, the production of electricity is made possible using a Rankine cycle [8]. Carnot efficiency of the process is

$$\eta_{\mathrm{Carnot}} = (T_E - T_c)/T_E = 20/298 = 6.7\ \%, \quad (3)$$

where T_E and T_c are hot water and cold water temperature respectively, K.

OTEC gross power efficiency is only half the Carnot limit - about 3%.

The systems can be classified into closed, open and hybrid cycle type. The open cycle conversion is accompanied by water desalination. The recent developments are reviewed in [8, 13], including improved variants with higher efficiency, Kalina cycle and Uehara cycle, using two component working fluid [14].

The Balkan region is out of the range of the potential sites between 20^{o}N and 20^{o}S for development of OTEC systems, but there are solutions using hot spring water or hot waste water [15], which are possibly feasible.

C. Salinity gradient conversion

In the review of salinity gradient conversion technologies [16] it has been noted that of all marine renewable energy sources the salinity gradient power is of the highest energy density, as shown in Table I. The osmotic pressure difference between fresh water and seawater is equivalent to 240 m of hydraulic head. Almost all of the proposed conversion schemes rely on the fundamental natural process of evaporation to separate the fresh water from the salt. The overview in [16] of the state of technologies till 2000 includes Pressure-Retarded Osmosis, Reversed Electrodialysis, Vapor Compression and Hydrocratic generator. The authors stated that any strategy to desalinate seawater could be reversed to produce power. The world's first osmotic energy plant has been operating from 2010 in Tofte, Norway, on the Oslo fiord inlet [17].

Aegean Sea, being the place of mixing of water masses of low salinity from the Black Sea and hypersaline water masses from Mediterranean Sea, which leads to formation of currents and water stratification with high salinity at the sea bottom, seems promising for development of marine power plants, but its potential has not yet been fully investigated and assessed.

D. Wave energy

Wave energy conversion is harvesting the power of the sea waves. When the wind energy is converted to wave energy, it is specially concentrated due to reduction of the area of energy distribution to the envisaged area perpendicular to direction of wave propagation. The power carried in the wave at the horizontal axis, per unit width of wave front at any instant [8], can be estimated by

$$P' = \frac{\rho g a^2}{2}\frac{c}{2} = \frac{\rho g a^2 \lambda}{4T} \quad (4)$$

where ρ is the sea water density, kg/m^3, a- wave amplitude, m, c- wave phase velocity, m/s, g- acceleration of gravity, m/s^2, λ-wave length, m, and T- period of motion, s.

The wave power levels near the coasts of the Balkan Peninsula are estimated to reach 7 kW/m of wave crest, [18], and near the Black Sea cost - 3 to 7 kW/m, [19], which is not as much as the potential of the North East Atlantic coast reaching to 70 kW/m, but marks the region as a prospective wave energy site.

The systems can be classified into fixed and floating or on-shore, near-shore and off-shore. Some examples of prototypes and plants put into operation are given in Figs. 6 to 10. The wave energy converting systems are reviewed in [20]. Most of the proposed processes of wave conversion are shown schematically in Fig. 11.

Examples of fixed on-shore converters are:

1. Oscillating water column (OWC), Fig. 6. Incoming waves force air up column to turn the turbine. Outgoing waves suck air down column to turn the turbine. LIMPET (Land Installed Marine Powered Energy Transformer) is a 500 kW rated OWC power plant, developed by the Queen's University of Belfast and Wavegen Ltd in the United Kingdom. A 75 kW prototype was constructed on the island of Islay, Scotland in 1991 [22, 23].

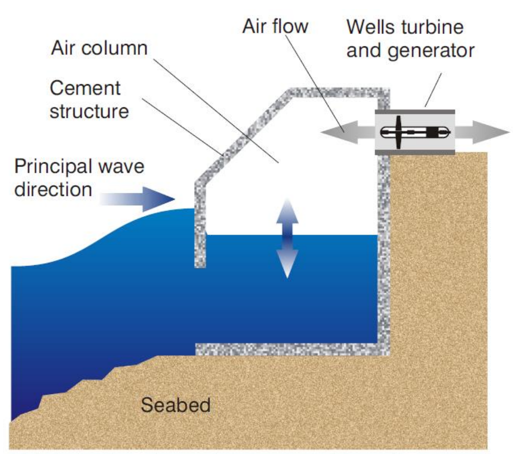


Fig. 6. Oscillating water column (OWC), source [24].

2. Tapered Channel System (TAPCHAN), where the concept is similar to that of traditional hydroelectric devices. Waves feed through tapered channel into reservoir and are then fed through a turbine. Kinetic energy of the moving wave is changed to potential energy as water is collected in the reservoir, Fig. 7. The TAPCHAN is designed by Norwave company, and a 350 kW prototype commenced operation in 1985 on a small Norwegian island.

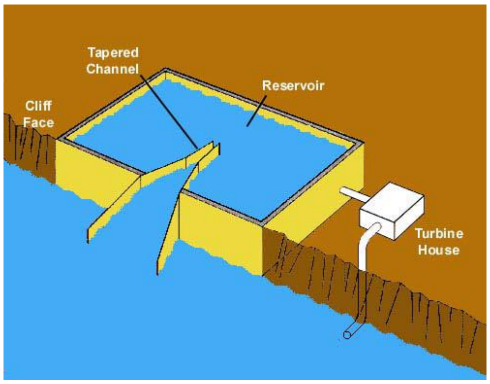


Fig. 7. TAPCHAN, Copyright Boyle, 1996, source [19].

The existing very large variety of off-shore floating devices is reviewed in the [24] and [20]. Some key examples of off-shore systems put into operation are:

1. The PELAMIS device, Fig. 8, consists of semi-submerged cylindrical sections linked by hinged joints, [25]. The wave induced motion of these joints is resisted by hydraulic rams which pump high pressure oil through hydraulic motors via smoothing accumulators. The prototype, a 120 m long and 3.5 m diameter device rated at 375 kW, was first tested at the European Marine Energy Centre in 2004 and became the first commercial scale off-shore wave power machine to successfully generate electricity into the national grid. The first prototype connected to the grid is currently deployed in Nissum Bredning fiord, Denmark in relatively mild wave conditions.

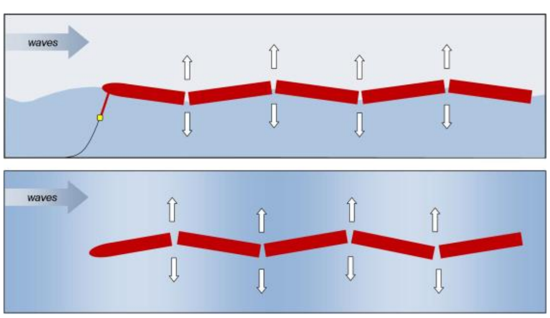


Fig. 8. PELAMIS wave energy converter, source[26]

2. The Archimedes Wave Swing (AWS), [27], is an off-shore, fully submerged (43 m deep underwater), point absorber (that is to say, of negligible size compared to the wavelength). Its two main parts are the silo (a bottom-fixed air-filled cylindrical chamber) and the floater (a movable upper cylinder). Due to changes in wave pressure, the floater heaves, Fig. 9. AWS Ocean Energy, the Scottish company established to commercialize the AWS, tested the technology at full-scale in open water (Portugal 2004).

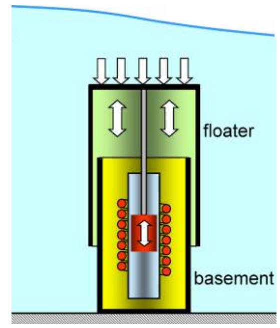


Fig. 9. Archimedes Wave Swing, source [28].

3. Wave Dragon, [29, 30], is a floating, slack-moored energy converter of the overtopping type. The overtopping device, Fig. 10, elevates ocean waves to a reservoir above sea level, where water is let out through a number of turbines and in this way transformed into electricity, i.e. a three-step energy conversion: overtopping (absorption); storage (reservoir); power-take-off (low-head hydro turbines).

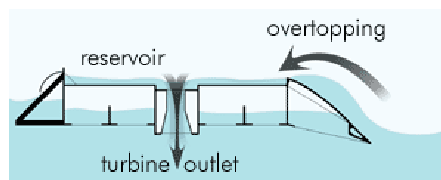


Fig.10. Wave Dragon principle, source [29].

The Wave Dragon prototype of rated power 20 KW tested in Nissum Bredning fiord in Denmark is constructed to match a very humble wave climate at approximately 0.4 kW/m, but the technology has no up-ward restriction from wave heights or wave lengths on its size.

III. MARINE ENERGY CONVERSION IN THE BALKAN REGION

The Balkan region is behind the development of the other European countries in respect to renewable energy resources. The reasons are lack of understanding and resistance of the authorities and the public towards the higher capital costs of the renewable energy, especially in the countries with economic and political difficulties. The authors believe that in this situation the strategy for successful marine power development of the region is cooperation of the researchers from the countries with close natural conditions and potential for higher efficiency and optimization of funding.

The aim of the present work is to show the basis for this cooperation, the engineering and scientific achievements in the area of marine power technologies in the Balkan countries, described as follows.

A. Wave power potential of Turkey

The wave power potential of Turkey was assessed in [31] with the aim to find out the cost effectiveness of a wave power converter system for the mild climate conditions of Turkish waters. 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 were suggested by the authors as the best sites to harness the wave energy and a system of the type of Wave Dragon was assessed in this conditions. It was concluded that the Baltic Sea and devices designed for that sea can be a sample for the studies in Turkey.

B. Sea current power of Greece

The work plan for marine power development in Greece given in the assessment of the energy potential of the Greek seas [32] can serve as a basis for the development of the Balkan region. The authors focused on measures for enhancement of the current measurement system and data base concerning speed/ direction of current/ wind, sea temperature etc. On the basis of a review of projects running in other countries the authors selected a vertical axis system (KOBOLD) [33] as a low-cost, easily deployable system ideal for the Greek seas. In addition SeaGen turbine would be an interesting alternative for covering large scale energy needs.

C. Wave power potential of Bulgaria

In the project report [34] the low-power wave conditions in the Black Sea and the large costs of the sea converters determine the aim of the studies – to develop devices which can be applied in sites of the world with better energy conditions for high capacity energy production or for small rescue vessels. On the basis of preliminary studies [35] in the Laboratory of Mechatronics at the Bulgarian Academy of Sciences on development of a wave converter utilizing the horizontal movement of the sea waves, an experimental device was constructed in 2010 and successfully tested in the sea [36]. The device floats on the sea surface and absorbs the wave energy by means of two vertical plates. A linear electric generator is connected to the plates moving back-and-forth. The device adapts to the changes of the wave length by changing the distance between the plates using only the power of the waves.

D. Wave energy conversion in sheltered seas

Very useful are the conclusions from the studies concerning sheltered seas, like the Baltic Sea and the Mediterranean Sea.

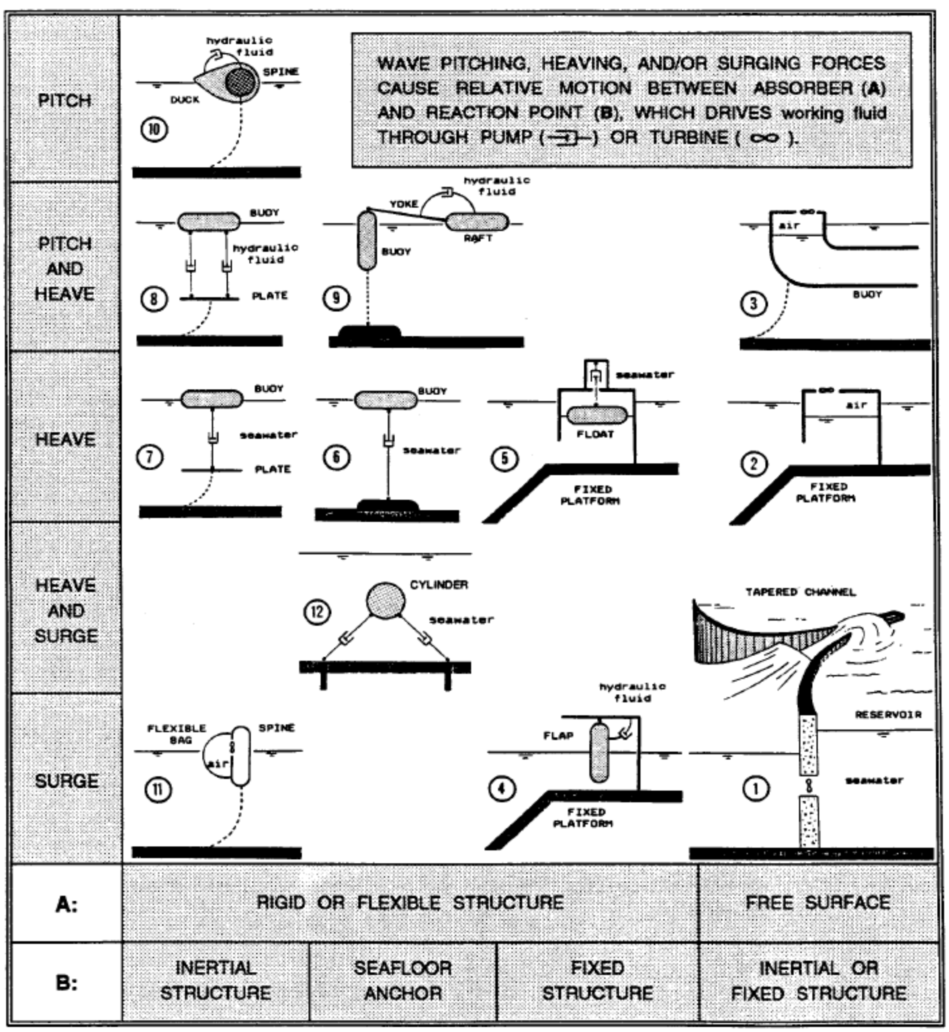
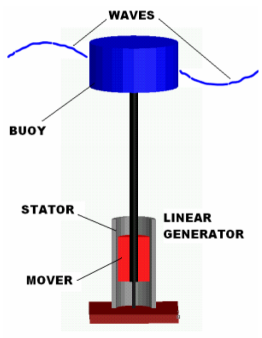


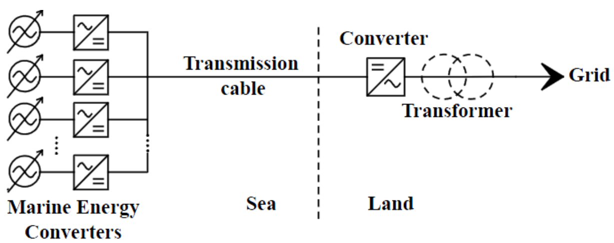
Fig. 11. Processes of wave conversion, source [21]

In the assessment of the potential of the Baltic Sea in [37] the dominating idea to use one large unit, which can convert a lot of power is opposed by systems where a number of small specifically designed generators are connected in arrays. The authors proposed for the sheltered seas with milder but steady wave climate, wave power plants consisting of a number of small wave energy converters, forming large arrays. They look at advantageous arrangements of point absorbers, [38], and their operation in the conditions of the Baltic Sea.

The concept of the wave power plants consisting of large arrays of small direct driven wave energy converters, having specifically designed linear generators driven by a point absorbing buoy, Fig. 12, was studied for the moderate climate of the Mediterranean Sea in [39] and for the Black sea near the Romanian coasts in [40].



a) the floating buoy system



b) the power system

Fig. 12. The direct drive power take off system, source [40].

The feasibility of the Seabased device [41], designed by Uppsala University for deployment in the Swedish seas, was studied in [39] for wave energy exploitation under Mediterranean Sea conditions by a numerical model of the coupled buoy-generator system, developed to simulate the behavior of the wave energy converter in regular waves of different wave heights and periods. The wave energy potential of the Black Sea near the Romanian coasts, a possible power take off system, Fig. 12, and respectively the linear generators to be used in such wave energy power converters was discussed in [40].

IV. THE UNIQUE POSSIBILITIES OF THE BLACK SEA

The Black Sea is unique with the presence of hydrogen sulfide dissolved in the water under the level of about 200 m depth, reaching constant concentration of 9.5 mg/l under 1500 m depth [42]. It is the world's largest anoxic basin, where almost 90% of the seawater is anaerobic [43]. The hydrogen sulfide in natural sea waters forms through bacterial sulfur cycle. The interest in production of hydrogen, the fuel of the future, is growing. Hydrogen sulfide can be converted to hydrogen and sulfides with much less energy than that required for splitting water [43]. Therefore many technologies are under development for hydrogen production from H_2S found either in industrial waste gases and waters or in natural sea water.

The potential for hydrogen and sulfur production from H_2S in the Black Sea is studied by many authors, especially from the countries surrounding the sea (Turkey, Romania, Bulgaria, Ukraine), and those using renewable energy sources, especially solar and wind are expected to be the most perspective [43]. The available methods for hydrogen production from H_2S at different stages of development include thermal, thermochemical, electrochemical, photochemical and plasmochemical methods [42]. In [42] a catalytic thermal decomposition process operated on solar energy for process heat generation is considered for hydrogen and sulfur production from H_2S in the Black Sea, Fig. 13. The authors selected the most promising site for such a plant, Amasra, Turkey, for the following favorable conditions:

- the 2000 m bathymetric contours pass nearest to the shore;
- sufficient insulation and solar radiation;
- mild wind and sea currents conditions;
- seaport and highway connection.

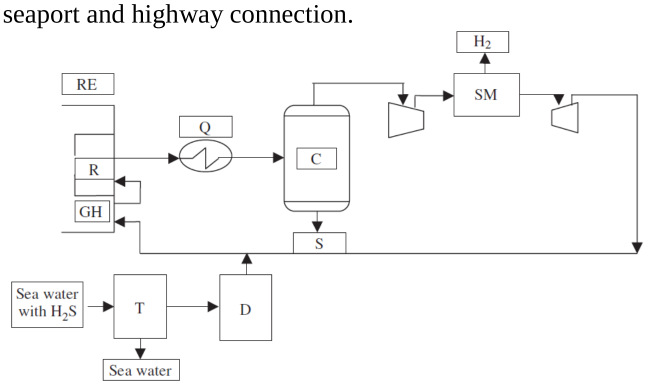


Fig. 13. Solar H_2S thermolysis process (C: condenser, D: dehumidifier, GH: H_2S heater, Q: quencher, R: reactor, RE: solar receiver, SM: membrane separator, T: sea water storage tank), source [42].

The authors of [43] proposed and studied a process of electrolysis of H_2S using renewable energy, Fig 14. Another technology under investigation, [44], is using electrochemical method of removal of sulfides from the deep Black Sea water by oxidation to sulfites or sulfates. The authors developed a fuel cell with a catalyst incorporated into activated carbon matrix.

The economical assessments [42, 43] show that no commercial technology has been developed yet. The high costs of the produced hydrogen and sulfur make the available solutions not economically feasible, but they have considerable ecological significance for counteracting the dangerous increase of the hydrogen sulfate content in the Black Sea.

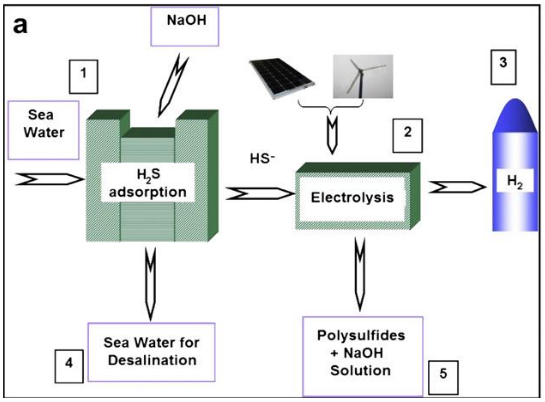


Fig. 14. Electrolysis of H_2S, source [43].

V. CONCLUSIONS

The present review of the current state of marine technologies for power production in the Balkan region aims at implications of further research and prospects. Although the energy potential of the seas surrounding the Balkan Peninsula is estimated as low power, sea energy conversion has its place, since large portions of the world marine energy potential are possessed by sheltered seas with mild conditions like the Mediterranean Sea, the seas surrounding the Balkan Peninsula and the Baltic Sea. The most promising for the region are expected to be wave and current energy conversion and decomposition of hydrogen sulfide from the Black Sea. For higher efficiency they can be combined with solar or wind converters. Because of the high cost for the development, installation, maintenance and testing of large-scale marine energy devices, the projects should be performed in cooperation of a number of countries and should be supported by national and European funds. It is necessary to promote international cooperation in the efforts to study and enhance the sea technologies in order to lower the cost of green energy production and to gain the support of the society and the governments. An important part of the studies is careful assessment of the social as well as environmental impact of the sea power technologies.

REFERENCES

[1] *ENERGY 2020 - A strategy for competitive, sustainable and secure energy*, Directorate Generale for Energy, EC, (2010, Nov.) [Online]. Available: http://ec.europa.eu/energy/publications/doc/2011_energy2020_en.pdf.

[2] M. Šturc, (2012, Nov. 8) Renewable energy .Analysis of the latest data on energy from renewable sources, *Environment and energy, EUROSTAT Statistics in focus*, [Online], Issue No *44*, Available: http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-SF-12-044/EN/KS-SF-12-044-EN.PDF

[3] *Electricity production and supply statistics* (2012) EC EUROSTAT, [Online], Available: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Electricity_production_and_supply_statistics

[4] J. D. Isaacs, W. R. Schmitt, "Ocean Energy: Forms and prospects", *Nature*, Vol. 207, Number 4428, pp. 265-273, 18 Jan. 1980.

[5] S. Alatsathianos, P. Fafali, "Wave and current energy: A viable scheme to exploit the energy potential of Greek seas", [Online], Available: http://www.researchgate.net/publication

[6] *Tidal Resources*, [Online], Available: http://www.see.murdoch.edu.au/resources/info/Res/tidal/index.html

[7] L B Bernshtein (1996) *Tidal Power Plants*. Seoul: Korea Ocean Research and Development Institute (KORDI). [Online], Available: http://repository.tudelft.nl/assets/uuid:46a59861-0817-4bf7-a252-b3a9562fdcd6/L.B._Bernshtein_-_Tidal_power_plants.pdf

[8] J. Twidell, T. Weir, *Renewable Energy Resources*, (2nd ed.), Taylor & Francis, 2006

[9] S. S. Khalid, Z. Liang, N. Shah, "Harnessing Tidal Energy Using Vertical Axis Tidal Turbine" *Research Journal of Applied Sciences, Engineering and Technology* 5(1) 2012, pp. 239-252, [Online], Available: http://maxwellsci.com/print/rjaset/v5-239-252.pdf

[10] J. Byrne, K. Baldwin, B. Celikkol, R. Swift, M. Wosnik, (2010, Feb. 11) Development of a tidal energy test platform, Univ. of New Hampshire, CORE, [Online], Available: http://www.mrec.umassd.edu/media/supportingfiles/mrec/agendasandpresentations/2ndconference/jeff_byrne_development_of_a_tidal_energy_test_platform.pdf

[11] Technology: Oscillating Hydrofoil, Marine Current Resource and Technology Methodology' Website: http://www.esru.strath.ac.uk/EandE/Web_sites/05-06/marine_renewables/technology/oschydro.htm]

[12] Sea Generation Ltd, [Online], Available: http://www.seageneration.co.uk/index.php.

[13] L.A. Vega, (1999) "Ocean Thermal Energy Conversion (OTEC)", [Online], Available: http://www.otecnews.org/portal/otec-articles/ocean-thermal-energy-conversion-otec-by-l-a-vega-ph-d/#economic

[14] H. Kobayashi, S. Jitsuhara, H. Uehara, (2001) "The Present Status and Features of OTEC and Recent Aspects of Thermal Energy Conversion Technologies", National Maritime Research Institute, Japan, [Online], Available: http://www.nmri.go.jp/main/cooperation/ujnr/24ujnr_paper_jpn/Kobayashi.pdf

[15] Nam Jin Kim , Kim Choon Ng , Wongee Chun, Using the condenser effluent from a nuclear power plant for Ocean Thermal Energy Conversion (OTEC), *International Communications in Heat and Mass Transfer*, 36, pp. 1008–1013, 2009.

[16] A. T. Jones, W. Finley, "Recent Developments in Salinity Gradient Power", *OCEANS 2003 Proceedings*, Vol. 4, 22-26 Sept. 2003, pp. 2284 – 2287.

[17] Tofte prototype plant, [Online], Available: http://www.statkraft.com/energy-sources/osmotic-power/prototype/

[18] V. Vannucchi, L. Cappietti and A.F.O. Falcão, "Estimation of the offshore wave energy potential of the Mediterranean Sea and propagation toward a nearshore area", *4th International Conference on Ocean Energy*, 17 October, Dublin, 2012, [Online], Available: http://www.icoe2012dublin.com/ICOE_2012/downloads/papers/day2/POSTER%20SESSION%202/Valentina%20Vannucchi,%20Universita%20Di%20Firenze.pdf

[19] V. Galabov, (2013) "On the Wave Energy Potential of the Western Black Sea Shelf", [Online], Available: http://arxiv.org/ftp/arxiv/papers/1304/1304.7806.pdf

[20] Feasibility of Developing Wave Power as a Renewable Energy Resource for Hawaii, (2002), Department of Business, Economic Development, and Tourism, [Online], Available: http://energy.hawaii.gov/wp-content/uploads/2011/10/Feasibility-of-Developing-Wave-Power-as-a-Renewable-Energy-Resource-for-Hawaii.pdf

[21] G. Hagerman, "Wave Energy Resource and Economic Assessment for the State of Hawaii," Prepared by SEASUN Power Systems for the Department of Business, Economic Development, and Tourism, Final Report, 1992

[22] Isley LIMPED Wave Power Plant, The Queen's University of Belfast Contract JOR3-CT98-0312 Publishable Rep., 1 November 1998 to 30 April 2002, [Online], Available: http://mhk.pnnl.gov/wiki/images/2/25/Islay_LIMPET_Report.pdf

[23] Technology: Oscillating water column (OWC) [Online], Available: http://www.wavegen.com

[24] Wave Energy in Europe Current Status and Perspectives, (2002) Centre for Renewable Energy Sources (CRES), [Online], Available: http://www.cres.gr/kape/pdf/download/Wave%20Energy%20Brochure.pdf

[25] R. Yemm, (1999) "The history and status of the Pelamis Wave Energy Converter", "Wave power – Moving towards commercial viability", *IMECHE Seminar*, London, UK

[26] Pelamis Technology, Pelamis Wave Power, [Online], Available: http://www.pelamiswave.com/pelamis-technology

[27] L. Hamilton (2006, Oct. 25), "AWS MK II. Deployment, monitoring and evaluation of a prototype advanced wave energy device", AWS Ocean Energy Ltd, [Online], Available: http://ec.europa.eu/research/energy/pdf/gp/gp_events/ocean_energy/1200_aws-mkii_en.pdf

[28] A. F. de O. Falcao, "Wave energy utilization: A review of the technologies, *Renewable and Sustainable Energy Reviews* 14, 2010, pp.899–918=

[29] J. P. Kofoed, P. Frigaard, E. Friis-Madsen, H. C. Sørensen, "Prototype testing of the wave energy converter Wave Dragon", *Renewable Energy*, Vol. 31, Issue 2, Feb. 2006, pp 181–189.

[30] Wave Dragon, [Online], Available: http://www.wavedragon.net

[31] M. Saglam, "Wave Energy and Technical Potential of Turkey", *Journal of Naval Science and Engineering*, Vol. 6, No.2, 2010, pp. 34-50

[32] S. Alatsathianos, P. Fafali, (2008) "Wave and current energy: A viable scheme to exploit the energy potential of Greek seas", [Online], Available: http://www.docin.com/p-385061618.html

[33] P. Kracht, J. Giebhardt, M. Lutz, M.Vecchio, A. Moroso, J. Bard, "Implementation of a Vertical Axis Marine Current Turbine for Off-grid Village Electrification in Indonesia", *4th International Conference on Ocean Energy*, 17 October, Dublin, [Online], Available:http://www.icoe2012dublin.com/ICOE_2012/downloads/papers/day1/1.2%20Tidal%20Stream%20Technologies/Peter%20Kracht%20-%20Fraunhofer%20IWES.pdf

[34] Innovation technologies for wind and wave energy in the coastal zone, INWECO (2009-2011), funded by the Bulgarian Science Fund , [Online], Available: http://waveconverter.alle.bg

[35] G. Stainov, "Device for converting the energy of the sea waves", Bulgarian Patent BG 66042 B1 (Priority Doc. 10.06.2008)(in Bulg.).

[36] B. Vassilev, G. Stainov, "Adaptive control of linear electro generator for experimental sea waves energy extracting device", *20th Int. Conference "ROBOTICS & MECHATRONICS '10"*, 6-9 Oct. 2010, Varna, Bulgaria, [Online], Available: http://waveconverter.alle.bg

[37] H. Bernhoff, E. Sjöstedt, M. Leijon, "Wave energy resources in sheltered sea areas: A case study of the Baltic Sea" *Fifth European Wave Energy Conference*, 17-20 September 2003, Cork, Ireland, [Online], Available: http://www.el.angstrom.uu.se/meny/artiklar/Wave%20energy%20resources%20in%20sheltered%20sea%20areas.pdf

[38] J. Falnes, *Ocean Waves and Oscillating Systems: Linear Interactions Including Wave-Energy Extraction*, Cambridge Univ. Pr. 2013.

[39] S. Bozzi, A. M. Mique, A. Antonini, G. Passoni, R. Archetti, "Modeling of a Point Absorber for Energy Conversion in Italian Seas", *Energies*, 6, 2013, pp. 3033-3051, [Online], Available: www.mdpi.com/journal/energies

[40] L. Szabo, C. Oprea, "Linear Generators for Wave Power Plants to Be Set up Near the Romanian Coasts of the Black Sea", [Online], Available: http://www.researchgate.net/publication/228680531

[41] M. A. Mueller, et al., "Low Speed Linear Electrical Generators for Renewable Energy Applications," *Proceedings of the Conference on Linear Drives in Industrial Applications, LDIA '2003*, Birmingham (UK), pp. 121-124.

[42] S. Z. Baykara, E. H. Figen, A. Kale, T. N. Veziroglu, Hydrogen from hydrogen sulphide in Black Sea, *International Journal of Hydrogen Energy* 32, 2007, pp. 1246 – 1250

[43] K. Petrov, S. Z. Baykara, D. Ebrasu, M. Gulin, A. Veziroglu, "An assessment of electrolytic hydrogen production from H_2S in Black Sea waters" *International Journal of Hydrogen Energy*,36, 2011, pp. 8936-8942

[44] E. N. Razkazova-Velkova, M. S. Martinov, L. A. Ljutzkanov, N. Dr. Dermendzhieva, V. N. Beschkov, (2013),Catalytic Oxidation of Sulfide Ions in Black Sea Water, *Journal of International Scientific Publications: Materials, Methods &Technologies*, Vol. 7, Part 1, pp. 456-463, [Online], Available: http://www.scientific-publications.net/download/materials-methods-and-technologies-2013-1.pdf.

Daniela Dzhonova-Atanasova was born in Vidin, Bulgaria in 1963. She graduated from the Technical University of Sofia, Bulgaria. There she received her MSc degree in Mechanical Engineering in 1988 and her PhD degree in 1992.

Her research interests are in the area of Heat and Mass Transfer Processes, Fluid Dynamics, Energy Efficiency in Chemical Engineering and Renewable Energy Resources. Since 1994 she has been working at the Institute of Chemical Engineering at the Bulgarian Academy of Sciences, Sofia, Bulgaria, as a researcher and Assistant Professor. Since 2011 she has been an Associate Professor at the Institute of Chemical Engineering. She was a lecturer in Fluid Mechanics at the Technical University of Sofia, and in Ocean Energy Conversion (in English) at the European Polytecnical University, Pernik.

Dr. Dzhonova is a member of the Union of Chemists in Bulgaria.

Rumen Popov was born in Plovdiv, Bulgaria, in 1964. He received the M.S. degree (Automatic Control Systems) in Technical University of Tula, Russia, in 1990 and the Ph.D. in Technical University of Ruse, Bulgaria in 2009.

From 1990 to 1991, he was a Research Engineer with the Aviotechnics SA, Plovdiv at Radio Electronic Systems department. Since 1991, he has been an Assistant Professor with the Control Systems Department, Technical University of Sofia, branch Plovdiv. He is the author of more than 45 articles. His research interests include Measurement and Automation, Renewable Energy Systems, Sun - Tracking systems.

He became an associated professor at the Technical University of Sofia, Bulgaria in 2011. His main courses are in Measurement Systems, SCADA Systems, and Aviation Electricity and Electronics. Assoc. Prof. Popov is a member of the Bulgarian Geothermal Association since 2011.

Aleksandar Georgiev was born in Dobrich, Bulgaria in 1958. He received the MSc degree in Mechanical Enginieering from the Technical University (TU) of Sofia, Bulgaria in 1981 and received the PhD degree in 1988 at the same university.

His research interests are in Renewable Energy Sources, Solar Heating and Cooling Systems, Sun - Tracking systems and Shallow Geothermal Energy.

He became a full professor at the European Polytecnic University in Pernik (EPU), Bulgaria. Prof. Georgiev is a member of the Bulgarian Geothermal Association since 2011. He is presently active at the Department of Mechanics at the TU Sofia, branch Plovdiv in Bulgaria.

His lectures (in Bulgarian and English) are in the field of the Thermal Energy Systems, they are hold in both universities (EPU Pernik and TU Sofia).