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AN OVERVIEW OF OFFSHORE RENEWABLE ENERGY RESOURCES

Abstract

Global reduction of fossil fuel reserves, as well as ascending awareness of human impact on overall climate change has significantly contributed to the development of renewable energy technologies. Inventive and emerging offshore renewable energy devices offer an opportunity to exploit huge and relatively unused energy potentials that can be exploited from sources such as wind, waves, tidal and ocean currents, thermal energy and salinity gradients. Current growing trends in global energy needs can be successfully and environmental friendly appeased by such kind of technologies. This paper represents an overview of offshore renewable energy potentials, different technologies, current status and applications as well as cost trends and major social impacts.

Key words: offshore renewable energy sources, wind, current, thermal energy, salinity gradient

PREGLED PUČINSKIH OBNOVLJIVIH IZVORA ENERGIJE

Sažetak

Smanjenje rezervi fosilnih goriva u svijetu, kao i rastuća svijest o ljudskom utjecaju na klimatske promjene značajno su doprinjeli razvoju različitih tehnologija obnovljivih izvora energije. Iznimno veliki i gotovo neupotrebljeni energetski potencijali energije vjetra, valova, mjenskih i oceanskih struja, termalne energije i gradijenta saliniteta mogu se uspješno koristiti pomoću različitih uređaja pučinskih obnovljivih izvora energije. Primjenom najnovijih saznanja u razvoju pučinske tehnologje može se uspješno i ekološki zadovoljiti rastuća potreba za energetskim resursima. Ovaj rad predstavlja pregled potencijala pučinskih obnovljivih izvora energije, različitih tehnologija, trenutačne primjene, troškova izgradnje i glavnih društvenih utjecajnih faktora.

Ključne riječi: pučinski obnovljivi izvori energije, vjetar, morska struja, termalna energija, gradijent saliniteta

1. Introduction

Global reduction of fossil fuel reserves, as well as ascending awareness of human impact on overall climate change has significantly contributed to the development of renewable energy technologies. One of the first and inventive attempts of offshore energy production dates back to 1970s, when concept and design of semisubmersible nuclear and gas plants were created [1, 2]. The first offshore renewable energy power plant was built in 1991 in Denmark with almost 5 MW of the total installed power produced by eleven wind turbines, [3]. Since that time energy production demands have significantly increased leading to development of many different types of renewable offshore energy production units using wind, waves, current, thermal or chemical energy, [3, 4], that can be considered as primemovers yielding electrical energy.

The current intensive offshore energy production development took place mainly due to limited possibilities of wind power plant construction on land related to noise problems, visual pollution, available locations with desired environmental properties and commercial difficulties related to land renting or purchasing. It has been therefore driven by a strong ambition of exploiting huge and unused energy potentials that contributed particularly to the offshore primemovers attractiveness, [5, 6]. Inventive and emerging offshore renewable energy devices offer an opportunity to exploit huge and relatively unused energy potentials that can be exploited from sources such as wind, waves, tidal and ocean currents, thermal energy and salinity gradients. Current growing trends in global energy needs can be successfully and environmental friendly appeased by such kind of technologies.

2. Renewable energy resource potential

Two basic types of resource potentials can be identified, i.e. theoretical and technical one, depending on the physical and technical properties. The former, although accurately quantified, does not have practical relevance since it takes into account only natural and climatic parameters, while the latter considers practical constraints and energy losses and estimates the energy output obtainable by the implemented technology.

The global theoretical wind potential has been estimated to be about 6000 EJ/yr (1666666 TWh/yr), while the technical potential of onshore wind potential estimates differ from 70 EJ/yr (19400 TWh/yr) up to 450 EJ/yr (125000 TWh/yr) depending on the considered data and assumptions as well as technical development. Offshore technical potential estimates range from 15 EJ/yr (4000 TWh/yr) to 130 EJ/yr (37000 TWh/yr). For the purpose of comparison, global electricity production in 2008 was about 73 EJ (20200 TWh).

The theoretical potential of ocean energy technologies has been estimated to be 7400 EJ/yr (2055555 TWh/yr), while the technical potential estimates range from 7 EJ/yr (1900 TWh/yr) to 331 EJ/yr (91900 TWh/yr).

Theoretical and technical potential estimates, both for offhore wind and ocean energy are summarized in Table 1. More detailed data, with references estimation methods as well as considered natural, practical and technological issues taken into account can be found in [3,4].

3. Offshore wind energy converters

In general, the offshore renewable energy has been predominantly produced by using aerokinetic and hydrokinetic devices. The former stands for devices placed above the sea surface and are driven by the atmospheric winds, while the latter are placed beneath the sea surface and are driven by the sea currents passing through the rotor disc, respectively. In that way rotational motion is induced and air or water kinetic energy is transformed into the electrical energy. One of the most prominent offshore aerokinetic energy extraction devices is horizontal axis wind turbine with fixed support structure (mainly monopile or gravity-base) as used in many countries over the world, e.g.

Sweden, United Kingdom, Belgium, Norway, Germany, China, [7]. A common installed power is between 2 MW and 4 MW for water depths up to 25 m with a clear trend of increasing turbine size. For sea depths between 30 m and 40 m the jacket supporting structure is commonly applied. Main effort of the current research activities focused on to reducing production costs and developing new technologies that would make possible to install the wind power plants in the deep sea by using different types of movable support structures such as spar, tension leg or semisubmersible support, [4, 7], as shown in Figure 1.

Table 3. A summary of theoretical and technical offshore renewable energy potentials

Tablica 1. Teoretski i tehnički potencijal pučinskih obnovljivih izvora energije

	Offshore wind potential, EJ/yr	Ocean technology potential, EJ/yr	Total, EJ/yr
Theoretical	na	7400	7400 + wind
Technical	15 - 130	7 - 331	22 - 461

Due to a nearly flat sea surface, offshore wind turbine has some favorable properties. In particular, nearly constant average wind velocity at the hub height along with weaker atmospheric turbulence, as compared to the wind developing over land, results with higher operating efficiency and lower structural fatigue of the wind turbine. Among other benefits, for offshore wind turbines it is possible to use longer wind turbine rotor blades for the same height of the wind turbine in comparison to the onshore wind turbines that yields more energy offshore than onshore. On the other hand, drawbacks are mainly related to demanding maintenance of offshore wind turbines, especially at high sea which requires development of special-purpose ship types. Hence, in order to design, manufacture, install and maintain such a complex offshore engineering structure operating in an aggressive meteorological and corrosive environment, highly specialized engineering knowledge and skills are required. More detailed overview of the present status, challenges and different technical and operational aspects related to offshore wind power plants can be found in [8, 9].

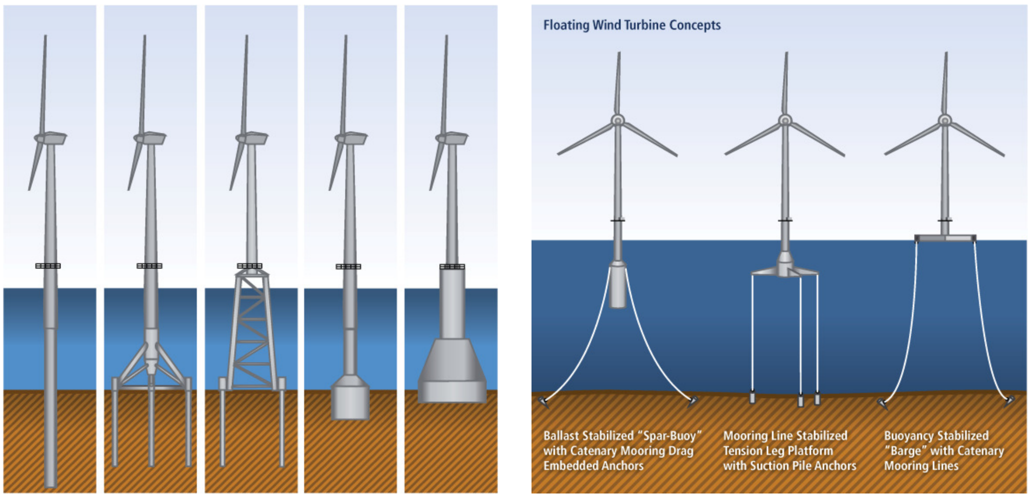

Fig. 1. Different types of fixed and floating offshore wind turbine supporting structure, [3]

Slika 1. Primjeri nepomičnih i plutajućih podkonstrukcija pučinskih vjetroturbina, [3]

4. Offshore sea current energy converters

A development of offshore wind turbines is accompanied by new and inventive hydrokinetic technology representing a set of devices driven by waves, tidal, river or ocean currents, [7, 10, 11].

At this moment, significant scientific, engineering and financial resources are focused onto development and commercialization of this challenging technology, especially with respect to tidal and current energy converters, [11, 12].

Most prominent representative of emerging hydrokinetic technology is horizontal axis tidal turbine (HATT), Figure 2, due to many favorable properties. Some important advantages of the HATT as compared to the wind turbines lie in the fact that the water density is about 830 times larger than the air density that enables the extraction of the same amount of energy across the considerably smaller rotor disc area making in such a way the HATT structure considerably smaller than the wind turbine that consequently enables easier, simpler and less expensive manufacturing, handling, transport, installation and maintenance. In addition, as the HATT device is placed below the sea surface, many environmental problems that apply to wind turbines above the sea do not exist for this case, such as for example visual pollution and obstacle for sea routes.

Another important advantage in comparison to other renewable sources is high predictability of sea currents that simplifies their design and ensures favorable exploitation conditions. Some drawbacks are related to corrosive sea environment, sea fouling, non-uniform velocity profile of sea currents due to a friction between the sea flow and possibly rough sea bottom as well as possible underwater noise. Current research activities with respect to the HATT devices are predominantly focused on possible application of knowledge and expertise gained through development of wind turbines above the sea surface as well as of marine propellers, since the development of the HATT devices is predominantly initiated through those two mature scientific fields. At this point, several HATT full-scale prototype installations have been commissioned, mainly in the United Kingdom, Ireland and Scotland with turbine installed power between 1 MW and 2 MW, usually in water depths up to 35 m, [7]. There are several supporting structure types, i.e. for tidal current devices monopile, gravity or jacket substructure is commonly applied, while moored floating structure replaces fixed substructure for deep water applications, usually for ocean sea current applications. Both fixed and floating type turbines can also operate in improved hydrodynamic conditions by increased performance if ducted configuration is deployed using shrouded rotor.

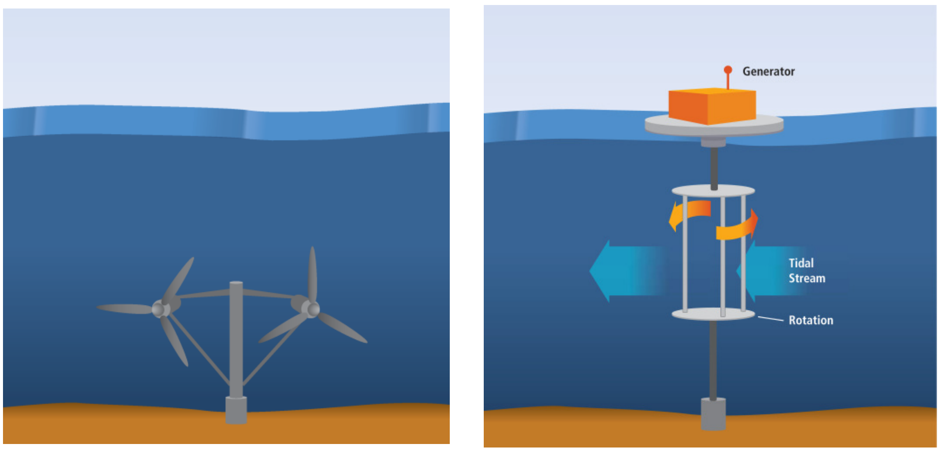

Fig. 2. An example of the horizontal and vertical axis tidal turbines, [4]

Slika 2. Primjer podvodnih pučinskih turbina s horizontalnom i vertikalnom osi vrtnje, [4]

5. Wave energy converters

Different types of wave energy converters have been developed in a wide range of operating conditions in order to convert wave energy into its usable form. They differ primarily with respect to the type of their interaction with wave motion (heaving, surging, pitching), as well as with respect to the water depth (deep, intermediate, shallow) and distance from the shore (offshore, nearshore, shoreline). Their generic scheme consists of three components, i.e. primary interface that interacts with fluid and transfers its energy to the second subsystems that incorporates direct drive or serves as short term energy storage. The third interface converts energy by means of electromechanical processes. A general classification of wave energy converters based on their operational principles is given in Figure 3, [4].

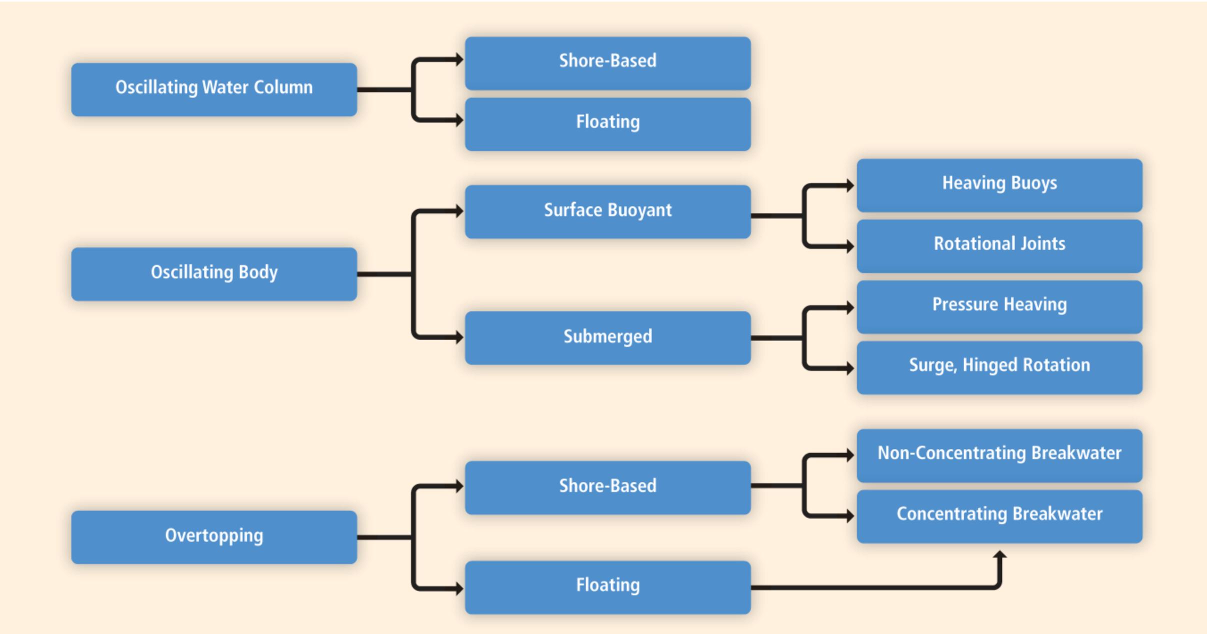

Fig. 3. Classification of wave energy converters, [4]

Slika 3. Klasifikacija uređaja za pretvorbu energije valova, [4]

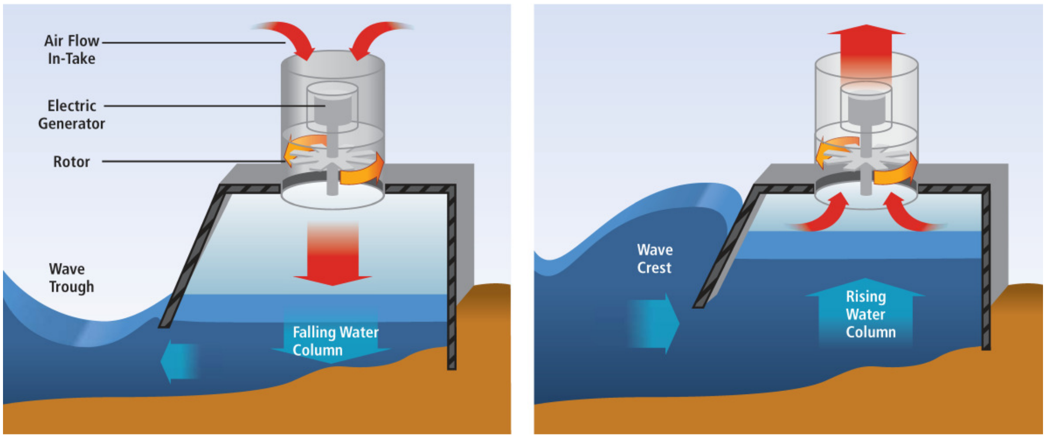

Fig. 4. Oscilating water column, [4]

Slika 4. Oscilirajući stupac vode, [4]

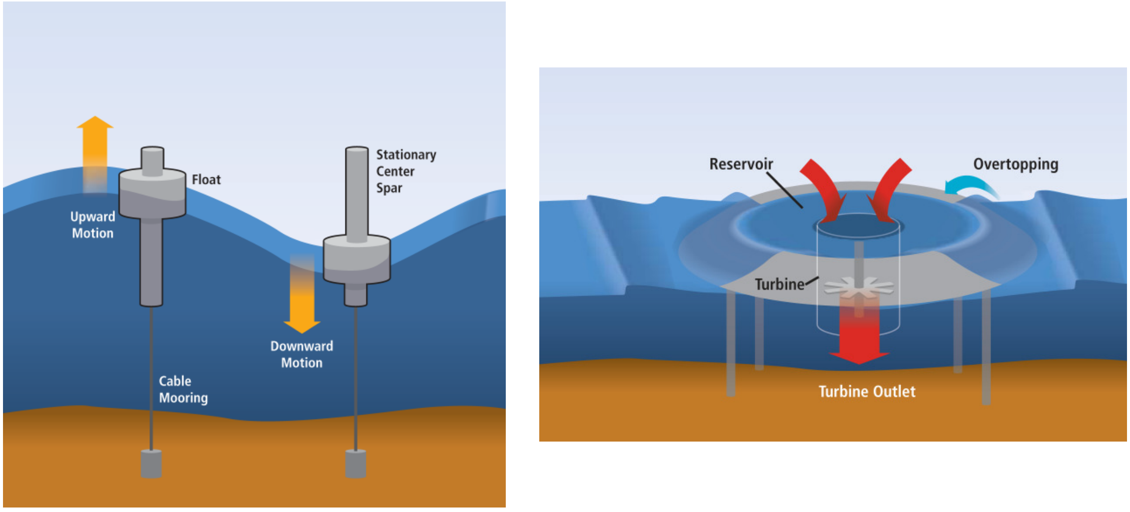

Fig. 5. Oscilating body and overtoping device, [4]

Slika 5. Oscilirajući plovak i uređaj s naplavljivanjem, [4]

Principal methods of wave energy conversion are oscillating water columns, oscillating body system and overtopping devices, Figures 4 – 7, respectively. Oscillating water column devices, Figure 4 and 5, convert wave energy by means of varying air pressure induced by wave motion. Air exhausts through an air turbine inducing its rotation, and consequently its kinetic energy is transformed into electricity. On the other hand, oscillating body system, Figure 6, also known as the point absorbers, transform wave induced heaving motion into electricity by means of relative motion of two bodies. Several applications dealing rotational motion induction can also bee found in the literature, [4]. A prominent example of energy storage conversion units is an overtopping device, Figure 7. Its basic operational principle is transformation of wave kinetic energy into potential by means of water accumulation. Once accumulated it is drained through the hydraulic turbine in order to induce its rotational motion.

6. Offshore thermal and salinity gradient converters

Offshore thermal energy converters are generally classified according to the operating scheme, i.e. as open, closed or hybrid converters. Being the most efficient, closed cycle thermal conversion is based on the vaporization and pressurizing of the secondary, turbine driving, fluid (ammonia, propane or chlorofluorocarbon) by means of warm surface water being pumped through heat exchanger. Several applications encountered various maintenance problems, indicating that such technology requires a significant scientific and technical development in order to become profitable.

Salinity gradient converters are the only conversion devices strictly related to the costal line since they utilize the energy released due to mixture of freshwater and seawater. There are two operating principles, first one based on the voltage induced by the alternating series of anion and cation exchange members while in contact with freshwater and seawater, and the second one based on the osmotic pressure difference. More detail related to this technology can be found in [4].

7. Comparison of offshore renewable energy resources

A comparison between different offshore renewable energy resources with respect to the maximum installed power, investment price, maintenance cost and operating period is given in Table 2. It can be noticed that the largest installed power is associated with offshore wind turbine, primarily due to its large dimensions that consequently result with a high maintenance cost. Therefore, a corresponding set of small scale devices, like sea current or wave energy converters could finally result with a greater profit. Quite large investment price range is associated to the sea current converters mainly due to small number operating units. Generally speaking, its price should be significantly below the investment cost of offshore wind turbines, especially when scale properties are considered.

Table 4. A comparison between different offshore renewable energy sources

Tablica 2. Usporedba različitih pučinskih obnovljivih izvora energije

Source	Maximum installed power, kW	Investment cost, $/kW	Maintenace cost, $/kW	Operating period, years
Offshore wind	4000	2000 – 5000*	170 - 350	20 - 40
Sea current	2000	4500 - 14300	100 - 140	20 - 40
Waves	750	6200 - 16100	180	20
Thermal energy	100	4200 - 12300	na	20
Salinity gradient	na	na	na	20

*Only offshore turbines with fixed substructure

8. Major social impacts

Important social benefits could be gained from the development of an offshore renewable energy technology. Except being environmental friendly during the operation stage, renewable energy source technology could create new (including high-tech) jobs, as well as added value to the global industry, especially shipbuilding, since it would enhance the production, installation and maintenance of such complex engineering structures. This refers to new challenges in knowledge and skills for planning, designing, execution of the whole project (general design, production planning, installation planning, logistics, engineering supervision, education of specialized staff, maintenance and safety organization).

Another key issue is reviving the Croatian shipbuilding industry, once one of the leading shipbuilding industries worldwide, with a potential to develop, design and produce specialized complex ships with high added value e.g.: heavy lift vessel, wind turbine installation unit, jack up vessel, offshore supply vessel, cable laying ship, dredger and floating crane. At this moment, the Croatian shipbuilding industry is in the phase of production diversification considering a synergy between shipbuilding and energy industry, as both industries have numerous common characteristics. In particular, the final product dimensions in both industries are similar. They both deal mainly with steel and welding, forming, bending and casting processes, which enables to use the existing equipment in shipyards. Moreover, the Croatian shipyards have a necessary experience, [13, 14], and production capacities (large workshops, cranes etc.), which can easily satisfy technology requirements with respect to onshore and particularly offshore wind turbine production. In particular, towers, nacelle heavy castings, substructures for fixed turbines and floating platforms for the floating structures. Another critical point is a strategic geographical location of the Croatian shipyards that makes them very attractive, since nowadays the largest cargo transport takes place by the sea.

9. Conclusion

Offshore renewable energy sources are outlined in this paper and their main properties and operating principles are pointed out. A particular focus is given on their comparison with respect to the maximum installed power, investment and maintenance cost, as well as expected operating and revenue period. Except that, several social impacts are considered and significant benefit for

Croatian shipyards is pointed out, since renewable energy production using the experience and shipyard facilities could significantly contribute to the overall Croatian economy.

References

[1] SLADOLJEV, Ž.: Zagreb's floating plant design offers alternative sitting possibilities, Nuclear Engineering International, June 1977, 32-33.

[2] SLADOLJEV, Ž.: Semisubmersible energetic objects, Maritime proceedings 19/1981, Rijeka, 1981 (in Croatian).

[3] WISER, R., YANG, Z., HAND, M., HOHMEYER, O., INFIELD, D., JENSEN, P.H., et al.: Wind energy. In: Edenhofre O, Pichs-Madruga R, Sokona Y, Seyboth K, Matschoss P, Kadner S, Ywickel T, Eickemeier P, Hansen G, Schlömer S,Von Stechow C, editors. IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation, Cambridge University Press, Cambridge, United Kingdom, 2011, 535-607.

[4] LEWIS, A., ESTEFEN, S., HUCKERBY, J., MUSIAL, W., PONTES, T., TORRES-MARTINEZ, J.; Ocean energy. In: Edenhofre O, Pichs-Madruga R, Sokona Y, Seyboth K, Matschoss P, Kadner S, Ywickel T, Eickemeier P, Hansen G, Schlömer S,Von Stechow C, editors. IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation, Cambridge University Press, Cambridge, United Kingdom, 2011, 497-534.

[5] O'KEEFFE, A., HAGGETT, C.: An investigation into the potential barriers facing the development of offshore wind energy in Scotland: Case study – Firth of Forth offshore wind farm. Renewable and Sustainable Energy Reviews, 16, 2012, 3711-3721.

[6] BILGILI,. M., YASAR, A., SIMSEK, E.: Offshore wind power development in Europe and its comparison with onshore counterpart. Renewable and Sustainable Energy Reviews, 15, 2011, 905-915.

[7] BRENNAN, F.P., FALZARANO, J., GAO, Z., LANDET, E., LE BOULLUEC, M., RIM, C.W., et al.: Offshore renewable energy. In: Fricke W, Bronsart R, editors. 18th International Ship and Offshore Structure Congress (ISSC 2012), Schiffbautechnische Gesellschaft, Hamburg, 2012, Vol. 2, 153-199.

[8] PARVEEN, R., KISHOR, N., MOHANTY, S.R.: Off-shore wind farm development: Present status and challenges. Renewable and Sustainable Energy Reviews, 29, 2014, 780-792.

[9] NGUYEN, T.H., PRINZ, A., FRIISØ, T., NOSSIM, R., TYAPIN, I.: A framework for data integration of offshore wind farms. Renewable Energy 60, 2013, 150-161.

[10] BEN ELGHALI SE, BENDOUZID MEH, CHARPENTIER JF.: Marine Tidal Current Electric Power Generation Technology: State of the Art and Current Status. IMDC, Antalya, 2007, 1407-1412.

[11] REED, M.C.: Evaluate, Asses, Develop, How the Department of Energy's Water Program is enabling MHK technology advancement. Marine Technology, July 2013, 52-58.

[12] AINSWORTH, D.: Harnessing Tidal Velocity. Marine Technology, July 2013, 33-38.

[13] BEGONJA, D.: A 12000 kN Capacity Catamaran Crane Vessel Design. The 8th Symposium Theory and Practice of Naval Architecture, Zagreb, 1988.

[14] SENJANOVIĆ, I., ČORIĆ, V., BEGONJA, D.: Structure Design of a Catamaran Crane Vessel. Brodogradnja 40(1-2), 1992, 21-34.