Bioengineering technologies used for the development and equipment of complex installations to obtain energy from three renewable sources. Complex installations for coastal areas

George Poteraș¹, Gyorgy Deak¹, Andreea-Georgiana Baraitaru¹, Marius Viorel Olteanu¹, Natalia Simona Raischi¹, Dewi Suriyani Che Halin²

¹National Institute for Research and Development in Environmental Protection Bucharest, 294 Splaiul Independentei, 6th District, 060031, Bucharest, Romania
²Centre of Excellence Geopolymer and Green Technology (CEGeoGTech), School of Materials Engineering, Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia

E-mail: marius.olteanu@incdpm.ro

Abstract. Considering that the production of energy from fossil sources causes environmental pollution, increasing health hazards or climate change, the research for new alternative energy sources and the development of high-performance renewable energy conversion systems are a basic concern nowadays. Thus, the development and the use of renewable energy sources can increase diversity in energy supply markets, help to ensure long-term sustainable energy resources, to reduce local and global air emissions, and provide commercial attractive options to meet the specific needs of energy services. This paper aims to improve the efficiency of a patented complex installation which was developed vertically to ensure high-energy efficiency in relation to the occupied area, that integrates three renewable energy sources (wind, solar and hydro), by applying bioengineering solutions. Improvements to the original installation consisted in modifying the initial characteristics of the off-shore system (number of slots, deflectors angle, width of slots and width of deflectors), modification of aerial module blades according to the bioengineering model of the thistle seed (Carduus nutans), and modification of the submerged module paddles according to the bioengineering model of a fish species swimmers. Following the tests performed on the modified complex installation, a major improvement of the energy efficiency compared to the (initial) control installation was observed.

1. Introduction

The widespread use of renewable energy has become an urgent necessity nowadays, being the only way to reduce greenhouse gas emissions without affecting the development of human society. The renewable energy potential on our planet is huge, and it is important to find solutions for its efficient use, at low cost and without producing a significant impact on the environment.

Hydropower plants account for about 16% of global electricity with a five times higher technical potential than the current utilization rate. At the same time, according to the forecasts of the US Energy
Information Administration (EIA), hydropower can contribute up to 16,400 TWh / year, and by 2050 the total installed hydropower capacity will double (1.947 GW = 0.001947 TW), generating an annual value of 7,100 TWh [1]. Wind turbines are relatively efficient machines, favorably comparable to other types of generation technologies [2], and accounting for land areas considered unsuitable for wind turbines installation (forested, urban and covered by either water or permanent ice areas), the potential energy source is estimated at 2,470 PWh / year (2470 TWh / year) [3].

The total installed capacity of solar energy reached 480 GW (0.48 TW) globally (excluding CSP) by the end of 2018, representing the second largest source of renewable energy after wind [4]. The current technically available solar potential has been estimated at around 613 PWh / year (613000 TWh / year) [5].

How can we capitalize the renewable energy potential that we have in an efficient way? The answer to this question was found by integrating three renewable energy sources in a single installation, with the highest efficiency in relation with the occupied area, due to its vertically development. The compact built surface and the secondary raw materials that can be used for several components manufacturing, determine a significantly lower cost for complex installation development. In terms of environmental impact, the traditional wind farms or photovoltaic panel farms present a negative landscape impact, and more than that, these are occupying significant areas of land that can have another destination (agricultural crops, pastures, forests, etc.). The implementation of complex installations in coastal areas significantly reduces these negative aspects.

A number of installations which are merging three renewable energy sources (wind, solar and hydro) have been reported worldwide, as being developed horizontally, located on a floating platform in their conventional forms - wind turbine, hydro turbine and solar panels, with a relatively large occupied surface [6,7,8]. The present paper has as a starting point a patented invention: Installation for the production of electricity from multiple renewable sources [9] and aims to improve the efficiency of the complex installation by applying bioengineering solutions.

2. Experimental

2.1. Methodology

Obtaining renewable energy from several integrated sources in a single complex installation is the most efficient way to obtain electricity in relation to the built area. If consider that such installations can be placed in coastal areas, with very low impact on the environment, similar to offshore oil rigs, the usefulness of these facilities is important.

2.2. Initial installation description

The complex system of electricity production (Figures 1-6) based on the cumulative effect of several renewable energy sources (hydraulic energy of waves or tides, wind energy and solar energy) combines two distinct modules: a cylindrical aerial module, which captures both, the energy of air currents and the solar energy and a submersible cylindrical module, which captures hydraulic energy. The aerial module is provided with a vertical axis with rotational speed multiplier coupling, located on a technological space. On the central axis, there are 8 rows of trapezoidal blades, arranged one in extension of the other and in perpendicular planes. Vertical slots for concentrating the air flow are provided on the cylinder generators, being adjustable by a deflectors system which also have a support role for photovoltaic panels. The submersible module, with a cylindrical shape, is attached to the aerial module, and the space resulting as a difference between the two diameters is used as a technological space, and present break-waves beams on the circumference. Vertical slots are provided on the cylinder generator, inclined towards the inner walls of the cylinder. The fastening device is similar to marine platforms and consists of tubular lattice beams. The electricity transformation / storage equipment is located in the technological spaces created both at the platform level between the two modules, and on the aerial module or on the fastening device.
Note: 1 - The aerial module; 2 - Submersible module; 3 - Rotational movement multiplier coupling; 4 - Technological space 1; 5 - Slot with 0.20 m width and 9.55 m length; 6 - Deflector with 0.70 - 0.80 m width and 10 m length; 7 - Photovoltaic cells; 8 - Technological space 2; 9 - Slot with 0.50 m width and 3.50 m length; 10 - Fastening device; 11 - Control cabin 1; 12 - Control cabin 2.

Figure 1. Complex offshore installation for renewable energy production [10].

Note: 1 - The aerial module; 2 - Submersible module; 3 - Rotational movement multiplier coupling; 5 - Slot with 0.20 m width and 9.55 m length; 6 - Deflector with 0.70 - 0.80 m width and 10 m length; 7 - Photovoltaic cells; 8 - Technological space 2; 9 - Slot with 0.50 m width and 3.50 m length; 13. Deflectors fastening system.

Figure 2. Complex offshore installation for renewable energy production – Deflector detail.
Note: 1 - The aerial module; 2 - Submersible module; 3 - Rotational movement multiplier coupling; 4 - Technological space 1; 5 - Slot with 0.20 m width and 9.55 m length; 6 - Deflector with 0.70 - 0.80 m width and 10 m length; 7 - Slot with 0.50 m width and 3.50 m length; 8 - Technological space 2; 9 - Slot with 0.50 m width and 3.50 m length; 10 - Fastening device; 11 - Rack; 12 - Axial bearing box; 13 - Pressure bearing box; 14 - Fastening system; 15 - Propellers with type 1 straight blades; 16 - Propellers with type 2 straight blades; 17 - Central axis with $\phi = 0.10$ m; 18 - Central axis.

Figure 3. Complex offshore installation for renewable energy production - A-A Section.

Note: 1 - The aerial module; 5 - Slot with 0.20 m width and 9.55 m length; 6 - Deflector with 0.70 - 0.80 m width and 10 m length; 8 - Technological space 2; 16 - Fastening device; 18 - Propellers with type 1 straight blades; 20 - Central axis with $\phi = 0.10$ m.

Figure 4. Complex offshore installation for renewable energy production - B-B Section.

Note: 2 - Submersible module; 9 - Slot with 0.50 m width and 3.50 m length; 19 - Propellers with type 2 straight blades; 20 - Central axis with $\phi = 0.10$ m.

Figure 5. Complex offshore installation for renewable energy production - C-C Section.
The two modules can work simultaneously or separately. When these work simultaneously a continuous movement with a constant speed, regardless of the wind force (the movement in case of strong winds is slowed down by the submerged blades) is obtained. When the two modules work separately, the central axis is interrupted using a coupling-decoupling device in case of storms that generate a high wind speed but also a high wave energy.

2.2.1. **Method of operation**. Renewable energies resulting from the movement of water waves, air currents or solar radiation, in favorable weather conditions, are collected separately and converted into electricity. If the weather conditions are unfavorable (cloudy sky, precipitation), the complex installation will operate using only renewable energy produced by air and water currents. If the weather conditions are totally unfavorable (storms, hurricanes), the installation can operate during this period by producing electricity only from water currents. In this situation, to protect the complex installation, the aerial module can be protected by closing the deflectors. Due to the fact that the aerial module axis can be coupled to the submerged module axis, through a coupling-decoupling device, the two modules can also operate simultaneously, the position of the deflectors being a determining factor in this case. The power of the complex offshore installation for renewable energy production from several sources depends on the useful surfaces that come into contact with the potential renewable energy sources, so the dimensions of the designed installation.

2.2.2. **Slots-deflectors System**. The role of the deflectors and the slot-deflector system is very important in the complex offshore installation for renewable energy production. First of all, the deflectors have the role of directing and concentrating the air flow through the slots, towards the turbine blades. The airflow entry angle through the slots can be modified, depending on meteorological parameters. On the other hand, the slot-deflector system is a bioengineering adaptation, inspired by the profile of birds wings during flight (figure 7).

**Figure 6.** Complex offshore installation for renewable energy production - Trapezoidal propeller detail for aerial module (type I) and submersible module (type II).
2.3. *Optimization of the aerial module blades efficiency by applying a bioengineering solution*

**Figure 7.** Sketches on the profile of bird wings.

The thistle seed (Carduus nutans) inspired the bioengineering model of blades for the aerial module of the complex offshore installation for renewable energy production from several sources, as seen in figure 8 and 9.

**Figure 8.** Blades for the aerial module of the installation developed according to the thistle seed model.
2.4. **Optimization of the submerged module paddles efficiency by applying bioengineering solutions**

Several bioengineering models have been experimented in various research carried out to establish the paddles profile. Of these, the pattern inspired by the swimmers shape of a fish species—figure 10 and figure 11—ensured a higher number of rotations, regardless of the waves amplitude.

**Figure 9.** Aerial module with blades developed according to the thistle seed model - sketch and functional laboratory model.

**Figure 10.** Paddles for the submersible module of the installation developed after a fish species swimmers model.
2.5. Optimization of the offshore complex installation for renewable energy production

To optimize the installation functionality, a numerical modeling which modified the initial characteristics was performed according to the table 1.

| Characteristics               | Dimensions                                    |
|-------------------------------|-----------------------------------------------|
|                               | Initial | After numerical modeling                     |
| Number of slots               | 16      | 8                                             |
| Tilt angle of deflectors      | variable| 50-55°                                        |
| Slots width                   | 0,10 m  | 0,60-0,70 m                                   |
| Deflectors width              |         | Proportional with slots opening               |

3. Results and Discussions

3.1. Optimization of the aerial module blades efficiency

The initial trapezoidal blades were tested under the same conditions as the blades developed after the thistle seed model. The tests were performed at three airflow speeds: 1.5 m/s, 1.8 m/s and 2.4 m/s. The results are presented in table 2:

| Air flow speed [m/s] | Rotational speed of blades [rot/s] | Trapezoidal | Thistle seed |
|----------------------|-----------------------------------|-------------|-------------|
| 1.5                  | 1.20                              | 2.26        |
| 1.8                  | 1.87                              | 3.15        |
| 2.4                  | 2.57                              | 3.50        |
The table shows that the blades developed by applying a bioengineering solution, imprint a higher rotational movement to the axis, compared to trapezoidal blades, regardless of the air flow speed. The highest increase was obtained at low air flow speed (+88%), followed by medium air flow speed (+68%) and maximum air flow speed (+54%). This aspect highlights the efficiency of this type of blades even at low speed air currents, when the rotational speed is almost doubled.

Based on the determinations made regarding the maximum power extracted from the turbines (table 3), it was observed a tendency to increase the value with increasing air velocity, both in the case of trapezoidal blades and in the case of blades inspired by the thistle seed model, but with a major difference in values between the 2 types of blades. For low, medium and high airflow speeds, the maximum extracted power increases progressively, being higher in the case of blades developed according to bioengineering models.

**Table 3. Values of the maximum power extracted from turbine.**

| Blades type | Airflow speed (m/s) | Maximum power extracted from turbine, P(W) |
|-------------|---------------------|------------------------------------------|
| **Trapezoidal** |                     |                                          |
|              | 1,5                 | 0,17                                     |
|              | 1,8                 | 0,15                                     |
|              | 2,1                 | 0,22                                     |
|              | 2,5                 | 0,71                                     |
| **Thistle seed** |                   |                                          |
|              | 1,5                 | 0,44                                     |
|              | 1,8                 | 0,72                                     |
|              | 2,1                 | 1,1                                      |
|              | 2,5                 | 1,55                                     |

Following the determination of the power coefficient (Table 4) as a function of relative (peripheral) speed, a maximum energy efficiency is underlined in the case of blades inspired by the thistle seed model, regardless of the wind input speed. In the case of trapezoidal blades, the efficiency according to this parameter is slightly lower, without a pattern depending on the values of the air current speed.

**Table 4. Values of power coefficient in relation with peripheral speed**

| Blades type | Airflow speed (m/s) | Power coefficient, Cp |
|-------------|---------------------|-----------------------|
| **Trapezoidal** |                     |                        |
|              | 1,5                 | 0,26                  |
|              | 1,8                 | 0,27                  |
|              | 2,1                 | 0,28                  |
|              | 2,5                 | 0,26                  |
| **Thistle seed** |                   |                        |
|              | 1,5                 | 0,3                   |
|              | 1,8                 | 0,3                   |
|              | 2,1                 | 0,3                   |
3.2. Optimization of the submerged module paddles efficiency

The initial paddles, also in trapezoidal shape, were tested similarly to the fish species swimmers bioengineering inspired paddles. The tests were performed for three qualitative amplitudes of the waves: low, medium and high amplitude. Table 5 presents the results:

| Paddles type                              | Waves amplitude | Rotational number / minute |
|-------------------------------------------|-----------------|---------------------------|
| Trapezoidal                               | Low             | 12                        |
|                                           | Medium          | 13                        |
|                                           | High            | 15                        |
| After the fish species swimmers bioengineering inspired model | Low             | 15                        |
|                                           | Medium          | 16                        |
|                                           | High            | 17                        |

Based on the results presented in the previous table it is observed that the paddles developed according to the bioengineering model, engage the axis in a superior rotational movement with 2-3 rotations / minute compared to the trapezoidal shaped paddles. More than that, it is also observed that the highest increase (+ 25%) is obtained at low amplitudes of the waves.

4. Conclusions

At the EU leadership level, it has been established that the share of renewable energy in the European space will reach in 2030 a value of 30% of the total consumed electricity. This requires an efficiency and diversification of renewable energy installations, so that the development of this sector to have the lowest possible impact on the environment. The complex installation for obtaining energy from three renewable sources located in the described coastal areas solves precisely these problems. The efficiency improvement of the complex installation was achieved by applying bioengineering solutions, both to the aerial module of the installation (slot-deflector system), and to the blades and paddles shapes. The slot-deflector system was inspired by the birds wings profile during the flight and has the role of...
directing and concentrating the air flow through the slots, towards the turbine blades. The blades developed according to a bioengineering model (of the thistle seed) showed a yield regarding the rotational speed with 58-88 % higher compared to the initial blades, the highest value being obtained at the lowest airflow speed. Moreover, in terms of maximum power that can be extracted from the turbine, the blades inspired by the thistle seed model present values of 2.6 times higher at low airflow speeds, from 4.8 to 5 times higher at medium airflow speeds and 2.1 times higher at high airflow speeds. Regarding the power coefficient, maximum energy efficiency is observed in the case of blades inspired by the thistle seed model, regardless of the wind input speed, while the trapezoidal blades have lower values, with a maximum in the area of medium air current speeds. The paddles developed according to the bioengineering model of a fish species swimmer also showed higher yields in terms of rotational speed by up to 25%, a value obtained for the lowest amplitude of the waves.

Acknowledgements
This work was supported by a grant of the Romanian Ministry of Research and Innovation, CCCDI – UEFISCDI, project number PN-III-P1-1.2-PCCDI-2017-0406/ Innovative Technologies for Renewable Energy Production from Integrated Natural Sources in Complex Installations - TEACHERS, within PNCDI III.

References
[1] International Finance Corporation 2015 Hydroelectric Power. A Guide for Developers and Investors (Stuttgart: FICHTNER)
[2] Royal Academy of Engineering 2014 Wind Energy implications of large-scale deployment on the GB electricity system (London: Royal Academy of Engineering)
[3] Lu X, McElroy M and Kiviluoma J 2009 Global potential for wind-generated electricity Proc. of the Nat. Academy of Sciences of the United States of America (Cambridge) 106 (27) pp. 10933-38
[4] IRENA 2019 Future of Solar Photovoltaic: Deployment, investment, technology, grid integration and socio-economic (Abu Dhabi: International Renewable Energy Agency)
[5] Korfiati, Gkonos C, Veronesi F, Gaki A, Grassi S, Schenkes R, Volkwein S, Raubal M and Hurni L 2016 Int. J. of Sustainable Energy Planning and Management 9 17-30
[6] Tunbjer Floating platform and energy producing plant comprising such a floating platform Patent no. WO 2014/055027 Al (release day: 10.04.2014) Furustigen 5 Stockholm
[7] Srinivasan N Offshore floating platform with ocean thermal energy conversion system Patent no. W O 2U1 1/139776 A1 (release day: 10.11.2011) Missouri City
[8] Sinn Power hybrid offshore platform - https://www.sinnpower.com/post/the-world-s-first-floating-ocean-hybrid-platform - accessed at 25.06.2020
[9] Poteraş G, Deak G, Monea M N, Neacșu I Instalație de producere a energiei electrice din multiple surse regenerabile Patent No. 131456/01.06.2016 (release day: 29.11.2018) INCDPM Bucharest
[10] Nicolae S F, Poteraş G, Deák G, Dăescu A I, Burlacu I F 2018 Journal of Materials Science and Engineering 3 (4) 173-183