Possibility of cogeneration from maritime and conventional energy sources for mining industry purposes.

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Abstract: Renewable energy sources in developed countries are usually considered as a possible alternative to traditional energy sources in the production of electricity and heat. Authors consider an importance of energy margin in regard to usability of renewable energy in mining industry. An original wave power plant is suggested as an additional energy source for some maritime mining operations and its features are thoroughly discussed.

1. Introduction

Over the last twenty years, renewable energy (RE), as a component of the energy industry, evolved from research and development activities to a full part of the energy balance in some regions and even countries (in Germany 23.4% of electricity production in the 1st quarter of 2014 was done by RE [10]. RE became one of the most blooming areas of existing energy markets transformation. By using the energy created from the air in the literal and figurative sense, many agents try to solve their problems with the provision of energy balances, which means that certain percentage of traditional energy sources are not being bought. The effect is not only purely economic or strategic, but also environmental – because of reduction of harmful emissions into the atmosphere. For some developing countries, this effect comes out on top in importance due to the existing problems in this area (e.g., persistent smog in Beijing).

The development of renewable energy sources is based on several determinants, including difficulty in solving environmental and other problems of the traditional energy, which do not find an answer in spite of many countries efforts; the emergence of new and improvement of old renewable energy technologies; general trends of the imminent transfer of the world developing economies to innovative ways of production.

In this paper, the authors try to identify the main types of renewable energy, to give brief description to them and their basic economic and energy parameters, to consider wave energy and describe its prospects. The problem of “energy returned on energy invested” index (EROEI), also called “energy efficiency”, will be also regarded from the RE point of view. In authors’ opinion it is very important to develop appropriate calculation methods for the binary systems of RE / traditional energy sources. Such systems (mainly natural gas in place of traditional energy) today are still a work in progress; a lot of ways to use them have not yet been investigated. The article describes cooperation possibility of the original wave installation together with gas generators. In the practical embodiment
of the mechanism on, for example, oil rigs, the effect in terms of the environment and the economy can be calculated in terms of money.

2. **Main features of renewable energy**

One of the RE features is the variety of ways in which people transform essentially the same solar energy in a more convenient form for themselves. There are, therefore, several types of renewable energy, and they differ from each other by costs of energy production and by EROEI (Energy Returned on Energy Invested – the ratio of energy produced to the consumed). Power margin is one of the most theoretically objective characteristics for the evaluation of projects in the energy sector, since it is the most reasonable estimate of their effectiveness—spread between how much energy people spend and how much they will get. In general, renewable energy sources in terms of EROEI can be defined as "sources of energy with persistent efficiency", as opposed to non-renewable sources, such as oil, whose EROEI performance has declined from 100 in the 1930s to 10–20 in the modern world, where it is necessary to conduct extraction on sea shelf in difficult conditions.

However, despite the convenience of such a measure, there are quite a lot of problems with the definition of the applicability limits of energy calculations of efficiency for a different kind of energy. For example, whether one wants to take into account all the energy that was spent on the construction of nuclear power plants, or one can focus on operational energy costs? It is because of these uncertainties disputes about renewable energy arise. By the example of EROEI, the table of different levels of the energy efficiency is shown [5].

| RE type         | EROEI          | Cents/kWh |
|-----------------|----------------|-----------|
| Hydropower      | 11:1 to 267:1  | 1         |
| Coal            | 50:01:00       | 2 to 4    |
| Oil (1930)      | 100:01:00      |           |
| Oil (modern)    | 19:01          |           |
| Nature gas      | 10:01          | 4 to 7    |
| Wind            | 18:01          | 4.5 to 10 |
| Wave            | 15:01          | 12        |
| PV              | 3.75:1 to 10:1 | 21 to 83  |
| Geothermal      | 2:1 to 13:1    | 10        |
| Coastal         | ~ 6:1          | 10        |
| High-viscous oil| 5.2:1 to 5.8:1 |           |
| Oil shales      | 1.5:1 to 4:1   |           |
| Nuclear         | 1.1:1 to 15:1  | 2 to 9    |
| Bio fuel        | 1.9:1 to 9:1   |           |
| PV (heat)       | 1.6:1          | 6 to 15   |
| Ethanol         | 0.5:1 to 8:1   |           |

In addition to this table it is possible to describe solar (photovoltaic) and wind energy more thoroughly. On the one hand, there are empirical data from Ch. Hall [4], in which wind energy has an EROEI 18 and PV 8. On the other hand, a lot of researchers claim that the calculation of these EROEI for RE is invalid, since it ignores the costs of additional processing and storage of such energy. So in the end there are parallel radically opposed views on the energy payback and efficiency [1,2]. There are also some researchers who state that RE is partly subsidized by social sphere [7]. Although having these kinds of divergent views, "green" energy is gaining momentum and is rapidly developing, as it is seen in Germany.
The hardest part is to solve the problem of the "peaks" and "instability" of these types of energy (Figure 1). RE has unstable supply, which requires constant backup and storage. One way to solve this problem is to use a dual system where the fall of the generation from renewable energy sources is covered by the work of traditional generators. Simulation of dual power systems requires special calculation algorithms that take into account these peaks and attenuation. For example, there are researches into solar-wind dual systems [3] or RE-nuclear pairs [12]. If one does not take into account these issues and problems with the power margin, the cost of a kilowatt-hour of solar energy in the south of Germany and the wind on the northern coast of Germany caught up with the kilowatt-hour produced at the combined-cycle plant with natural gas, and amounted to about 10 cents per kilowatt hour [9]. These data on the levelized energy costs were obtained by the Fraunhoffer ISE and are now one of the most basic and often-cited studies in the industry. It is worth mentioning, though, the fact that this level of costs is not worldwide – for example, USA, where RE is available as well as in Germany, traditional energy is still cheaper than RE.

Another type of renewable energy is "water power", which is represented mainly by hydroelectricity and tidal generation. Simply put it is the energy of rivers, ocean waves and tides. And if hydroelectricity is studied in detail – their cost-effectiveness is undeniable, then the energy of the waves is much less known, but this will be discussed later in the article. Due to the more permanent character of wave energy generation, previously suggested for PV-energy scheme will work with the wave power plants only in a simplified form.

In sum, it should be noted that, despite the development, undoubted evolution and progress of "green" energy in Europe, many questions concerning a particular economic efficiency remain, which, like almost any end product in the value chain, consists of a large number of indicators. The use of renewable energy in developing countries is complicated by objective problems and bypass for them that will be discussed later.

3. Wave energy plant (WEP)

Interest in the possibility of practical implementation of wave energy into technical devices appeared in the period between the 1900s and 1930s, when the first appearance of the first installation of 1 kW was recorded. Currently, several dozen original wave inverters are recorded by various patent bureaus every year beginning with the period that followed the oil crisis. The main advantage of this energy type is the enormous amount of energy that can be obtained from the ocean waves, and the percentage of conversion is sufficiently high. Today one can identify six generally accepted methods of power generation using waves: the first two are based on the interception of the wave motion in the
horizontal align (dot absorber surface and attenuator), on the vertical drop (overflow devices and columns), and on the conversion of wave motion vertically.

One of the devices of the first group converts the energy of the oscillating water column. When a wave is applied to a partially submerged cavity exposed under water, the liquid column in the cavity oscillates, causing pressure changes in the gas above the liquid. The cavity can be connected to the atmosphere through the turbine in one direction or the Welsh turbine can be used. One of the most successful attempts at the moment is the Oceanlinx wave power station in Port-Kemble, Australia. The main element that determines the efficiency of the wave power plant is a turbine. Due to the fact that the direction of the waves and their force are constantly changing, conventional turbines for generating wave energy are unsuitable. Therefore, the station Oceanlinx uses a Denniss-Auld turbine with an adjustable angle of blade rotation. One power plant Oceanlinx has a power (in peak mode) from 100 kW to 1.5 MW. The installation in Port-Kemble delivers 450 kW of electricity to the city's electricity grid. The principle of the wave power plant is that the waves passing through it pushes the special chamber with water, displacing the air contained in this chamber. Compressed air under pressure passes through the turbine, rotating its blades. As a result, electricity is produced. The advantage of this approach is that the speed of air passing through a pneumatic tube can be significantly increased by decreasing the passage section of the channel, which will allow combining slow wave motion with high-frequency motion of the turbine. However, the complexity of the design and significant size are the main disadvantages that prevent their wider distribution.

Another type of wave generators are installations that transform the wave profile. They are primarily related to the development of the University of Edna, Stephan Salter, named in honor of the creator "Salter duck ". The principle of this device is based on the use of an oscillating wing during the passage of the wave front. Reflecting and passing only a small part of the wave energy (about 5%), this device has a very high conversion efficiency in a wide range of frequencies of oscillations. However, this device is also not devoid of shortcomings. The main one is the need to monitor the direction of wave oscillations in order to obtain the maximum efficiency and, of course, the overall dimensions and shape of the device itself.

A similar version of the wave converter with a swinging element is the contour raft of Cockerel. Contour raft - multi-link system with hinged sections. Like the "duck", it is installed perpendicular to the wave front and tracks its profile. Detailed laboratory tests of the model of the raft on a scale of 1/100 showed that its efficiency is about 45%. This is lower than the "duck" of Salter, but the raft attracts another advantage: the proximity of the construction to traditional shipbuilding facilities. The manufacture of such rafts will not require the creation of new industrial enterprises and will allow employment to be raised in the shipbuilding industry. The pilot project of a similar wave power plant, Ocean Power Delivery, was implemented at the European Maritime Energy Center on the Orkney Islands in northern Scotland. The first commercial wave power plant has already been launched five kilometers from the northern coast of Portugal. The power plant, commissioned by Enersis, consists of three 750 kW modules each. The total capacity of the station is 2.25 MW, the generated electricity is enough to supply one and a half thousand houses on the coast.

The environmental effect of the use of Pelamis converters is impressive, which is a long (120 meters), round in diameter cylinder 3.5 meters in diameter, consisting of three modules connected by mobile communication. Each module has an electro-hydraulic generator with a power of 250 kW, specially developed by ABB. The use of one module with a capacity of 750 kW per year allows refusing from burning such an amount of organic fuel that would release 2000 tons of greenhouse gas CO2. The potential of Pelamis technology is huge. It is estimated that twenty wave power stations with a capacity of 30 MW can provide electricity to such a large city as Edinburgh.

Given the prospect of maritime energy trend, the National Mineral Resources University in St. Petersburg developed a new scheme for the wave energy plant (WEP), which is easy to build and use highly wear resistant parts in its the mechanism [11]. The wave power plant contains (see Figure 2) a vertical stand fixedly installed, for example, in the ground of a reservoir or on a rig support. In the reinforced housing there is a linear current generator consisting of a stator and a generating core
capable of vertical reciprocating motion inside the stator. The hollow box protects the linear electric current generator from moisture (rain, splashes of waves), and the non-metallic case is not corroded. This solution significantly simplifies the whole design in comparison with existing analogs.

Figure 2. Wave energy plant.

Like any other wave converters, this installation does not harm the environment, and under certain conditions can run continuously. This type of installation—stator moves while rotor remains stable—can lead to rather interesting effects in terms of economy and environment. Linear power generator allows you to get away from many of the problems of wind energy associated with numerous failures of engines and constant wear problems. Another important feature of the proposed plant is the lack of rare metals in the engine, because the design does not require any light alloys, like the ones needed for the blades of wind turbines or PV cells of solar panels. This should lead to a high EROEI by reducing Energy Invested component, as well as the low prices on the disposal of each unit. According to the site oilprice.com, for the period of “green” energy development in Germany there were about 25 thousand wind turbines installed and 7 thousand of them are approaching the date of replacement with recycling cost of a turbine around 33.5 thousands euro due to the cost of special equipment and labor costs.

Creation of a prototype by a patent scheme starts nowadays from economic assessment of its expected performance. The required procedure is greatly complicated by the previously mentioned problems, typical for the industry of renewable energy in general. To get funding for that prototype, it is necessary to calculate economic indicators, but due to the fact that the new specialized unit was created for use in a narrow field, there are no data about the costs of construction and operation. There are speculations about a possible price of energy from the wave sources—from 220 to 470 euro per MWh as mentioned in the budget the United Kingdom until 2020 [13], but they are quite uncertain. Without these data, it is difficult to use either cost or comparative approaches to the assessment of WEP, which means that there is only one option—profit evaluation. To use it, one has to describe the possible revenues from the proposed WEP, which, due to the uniqueness of the industry, one offers to evaluate through the potential demand for the products. Exemplary applications of the product are oil platforms, any stationary objects in the sea, coastal areas, and remote off the grid areas. The most promising segment are oil platforms, today burning its own resources for its energy supply, which is unsustainable, both from an environmental and economic point of view. In 2010, there were 389 oil platforms; by 2017, their number is expected to increase by 100 units, foretelling us quite promising market demand. On average an oil platform in the North Sea—the authors took the example of the Norwegian research data [8]—uses about two gas generators with a capacity of 23 MW, as the load on the platform is changed from 20 to 35 MW. On this average load average amount of emissions of carbon dioxide and nitrous oxide were calculated, with payments for these defined by law. That saves combusted gas emissions into the atmosphere and is regarded as a major economic effect within the above-mentioned study from 4.23 to 5.73 million euro for 4 wind turbines with total capacity of 20 MW. The difference of half a million is explained by differences in the proposed scheme of inclusion.
of generators. Despite the magnitude of the effect (which is more or less same for any RE used on oil platform), it should be noted that the installation of WEP to support oil platforms is a complex engineering task, which, perhaps, has no rational solutions. With exception of oil platforms, demand remains in remote areas and are self-supporting sea platforms. These two markets are not clearly limited, as oil platform, since these devices are in abundance and there are a lot of areas distant from the main power grids. For the evaluation of these market segments, it is possible to suggest using winds, solar and wave activity maps, imposition of which may suggest what type of renewable energy is more applicable to certain territories.

4. Conclusions

In conclusion, it is worth mentioning that the scope of research into issues such as development and economic evaluation of renewable energy is enormous, especially for developing countries. This is due to a constant innovation process in industry, lack of a basis for result comparison, a commercial secret of modern projects on this subject. Of special importance is a question of obtaining financing for the creation of the first prototypes for new technologies. The obvious fact is that the only reliable source of information on costs in the industry will be only their own experience, as all other sources of information are either interested in the issue or directly opposite to the first. Thus, according to the authors, in the assessment of investment projects in the sector of renewable energy, the most appropriate way to assess results is income approach in the early stages of a prototype work, and the cost approach after the R&D. Also to reduce the costs of research, R&D and the income approach assessment must be conducted simultaneously.

The use of renewable energy, together with energy-efficient equipment can provide significant economic and environmental benefits. The energy source is a device that converts wave energy into electricity or heat. At the same time, the considered source may be paired with a variety of potential energy-efficient and low-power devices, such as infrared heating systems, pumps and any appliances. Equally, the possibility to work together in a common network and with other energy sources is of interest. In all such systems, WEP can be used as a main power source proposed. Therefore, a comprehensive study of this source (being common to the various systems) will enable its wide application in many fields.

The environmental effect of the coupled systems that could be used instead of the traditional ones should be assessed separately and now there already are several attempts to evaluate it for the most common renewable energy sources. Unfortunately, the efficiency of energy requires additional studies, and hence the evaluation of coupled systems done at this moment can be incorrect due to mistakes in EROEI evaluation.

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