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Performance analysis of hybrid hydroelectric Gorona del Viento and the basic directions of its perfection.

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Abstract. The intensive development of renewable energy has led to the creation of a new type of hybrid power plants, which include several sources of energy and energy storage devices. The joint work of several different types of electric power generators requires careful study of operating experience in order to optimize their work. This paper is devoted to a detailed analysis of the effectiveness of the classical hybrid power station Gorona del Viento, located on the island of El Hierro (Canary Islands).

Key words

Hybrid power plants, renewable energy, energy storage.

1. Introduction

Global climate change, local environmental disasters and major accidents at energy facilities, as well as the foreseeable prospect of depleting fossil fuel reserves have forced humankind to look for alternative renewable sources of energy, such as solar and wind energy, wave energy, biomass and so on. While the share of renewable energy sources in the overall balance of energy production was small and amounted to about 10–15%, no difficulties arose. Renewable energy sources were simply a small addition to the main traditional generating facilities. All load fluctuations in the electrical network were regulated by changing the power of traditional generators using fossil fuels. However, as soon as the share of renewable energy begins to approach 50%, the situation changes radically. Renewable energy sources are becoming the main energy generator, and traditional generators using fossil energy sources are transferred to the standby energy sources mode. This situation has led in the last 5 years to the creation of hybrid power plants, which combine several different energy sources (renewable and conventional), as well as powerful energy storage systems of various types. At the same time, the existing hybrid power plants should be divided into two types. The first type of hybrid power plants is designed for autonomous power supply of an industrial facility or a small residential area. Examples of such power plants are solar hybrid power plants in combination with back-up gas piston generators. Also, in the composition of such power plants can also be wind turbines (Fig.1 and 2).

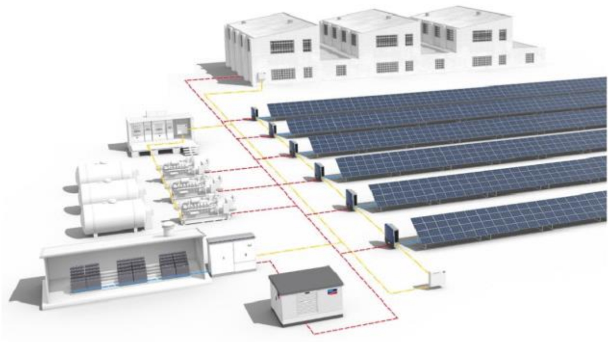

Fig.1. Hybrid solar power plant with back-up gas piston generators [1].

Fig.2. Hybrid power plant with a wind generator, solar photovoltaic panels and backup diesel generators [2].

The second type of hybrid power plant is designed to power a particular region or island, on which industrial and residential facilities are located. The principal difference between these two types of hybrid plants lies in the modes of operation. The first type of hybrid plants can be adapted and optimized for the power supply of a particular object with its specific features. The second type of hybrid systems has the same operating conditions as any large city or group of cities. At present, it is very important to carefully study and analyse the operating experience of hybrid plants of the second type. Today, on the continental part of Europe, the share of renewable energy sources does not exceed 25–30% and traditional power generators remain predominant. At the same time, on some islands the share of renewable energy sources has already exceeded 60%, which makes them the main generators of electrical energy. In a few years, a similar situation will occur on the mainland of Europe. That is why it is necessary today to study in detail the experience of hybrid power plants on the islands and optimize their parameters. Moreover, other types of hybrid plants can be tested on the islands using more modern technologies. This will allow to avoid all the mistakes in the construction of larger hybrid power plants in the mainland of Europe and other continents.

2. Hybrid Hydroelectric Station Gorona del Viento (Analysis of the effectiveness of the main elements)

Of greatest interest to study is the hybrid power station Gorona del Viento on the island of El Hierro. This project was implemented relatively recently, but the experience of its operation is already of great interest. The attitude of specialists to this project is very ambiguous. The authors of the project and their supporters of course positively evaluate the project and the results achieved [3],[4]. However, in some projects, there are some critical comments [5],[6]. First the very high cost of the project is being criticized, which causes doubts among the experts about the economic feasibility of this project. Of course, if we consider that the Gorona del Viento project is fully completed, then the logic in the critical remarks, of course, is.

Many renewable energy projects today have very low economic performance due to very high initial costs. However, if we consider the Gorona del Viento project in its current state only as the first stage of a large project to create a prototype hybrid power station of the future, then this project becomes simply unique. The basis laid in the project allows in real conditions to explore the most diverse energy storage technologies, which is extremely important for the future of energy. In mainland Europe, the share of renewable energy today is only approaching 30%, and on the island of El Hierro, this year indicators have been achieved twice as high. It is this fact that makes this project unique and extremely valuable for in-depth analysis and developing recommendations for improving the efficiency of hybrid power plants.

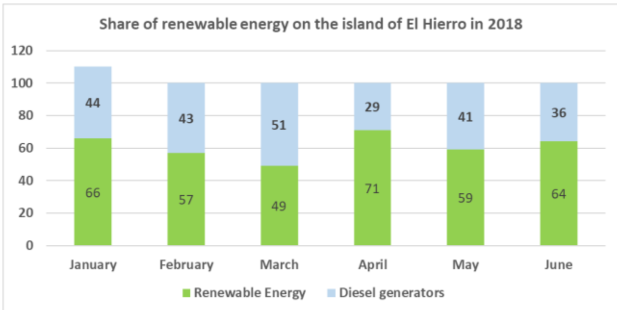

Fig. 3. The share of renewable energy sources (including hydroelectric energy storage) on the island of El Hierro in 2018 [7].

We should not forget that our ultimate goal is not to increase the share of using renewable energy sources, but to reduce CO2 emissions into the atmosphere. These are not always identical indicators.

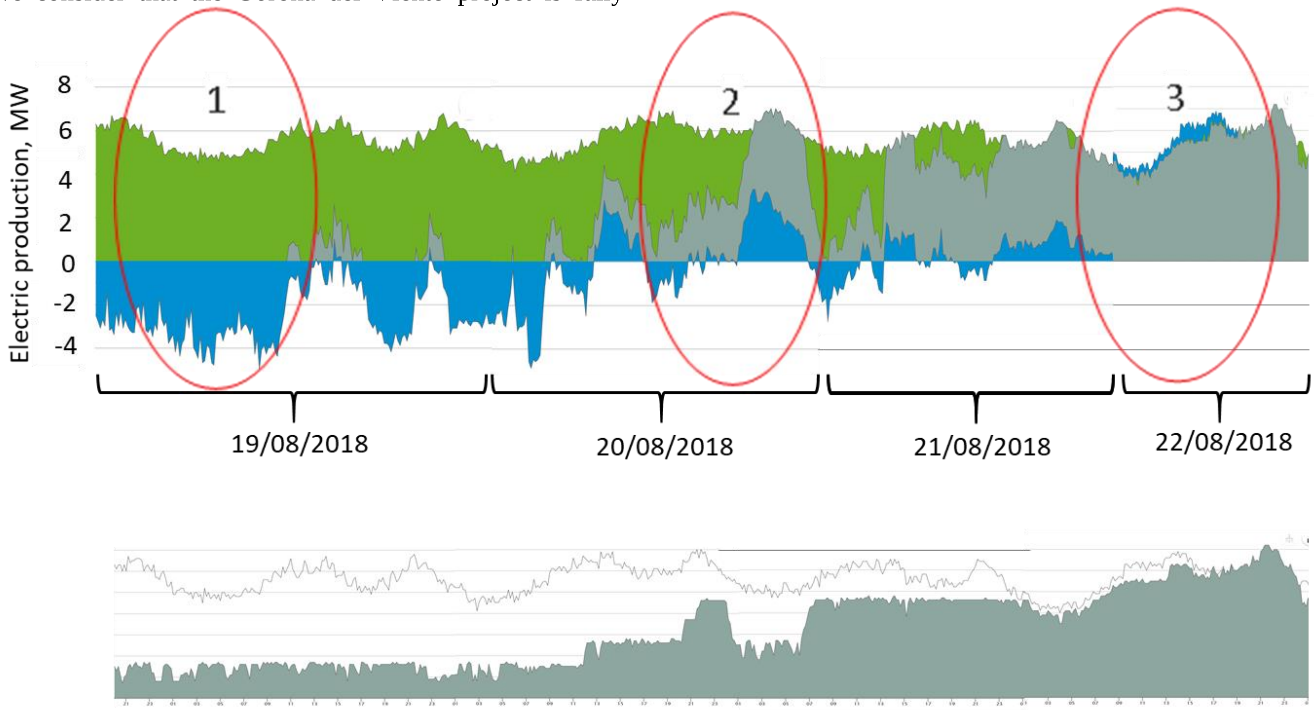

Fig.4. The schedule of operation of the power station Gorona del Viento for four days. The upper graph shows the total work of all elements: ■ - electricity production using wind generators; ■ - electricity generation using a pumped storage power station; ■ - power generation using backup diesel generators. In the lower graph, only the power of the backup diesel generators is highlighted (The graph is based on the statistical data given on the official website of Red Eléctrica de España S.A. [10]).

As long as conventional electric power generators are used, even if they are used as backup engines, the intensity of CO2 emissions and the atmosphere will be determined by the efficiency of conversion of the reserve fuel into useful electrical energy. Even if the share of renewable energy sources reaches a level of more than 50%, and inefficient installations will be used as reserve energy sources, there will not be a total reduction of CO2 emissions into the atmosphere.

In Figure 4, three most interesting areas for analysis should be highlighted:

1. The zone of primary use of renewable energy sources.
2. Zone of sharp transitions from one energy source to another.
3. Zone of primary use of reserve fossil fuel.

Zone 1 is characterized by intensive use of wind energy. The energy generated by wind turbines not only fully covers the needs of all consumers but is accumulated by pumping water into the upper reservoir of the pumped storage plant. However, as we can see, in the lower graph of Fig. 4, diesel generators also work, and their power level is about 20% of the total need for electrical energy. Why is this happening? Why run diesel engines and use reserve fossil fuels if there is an excess of electrical energy in the system? If you carefully examine the schedule in zone 1, it turns out that water is not pumped by a renewable energy source, and for this purpose diesel engines are used. The reason lies in the sharp fluctuations in the load in the electrical network. The power storage system is unable to provide a quick response to changes in the load on the network. This is the problem. Diesel engines are used to regulate the load in the electrical network. This is clearly seen from the graph in Fig.5.

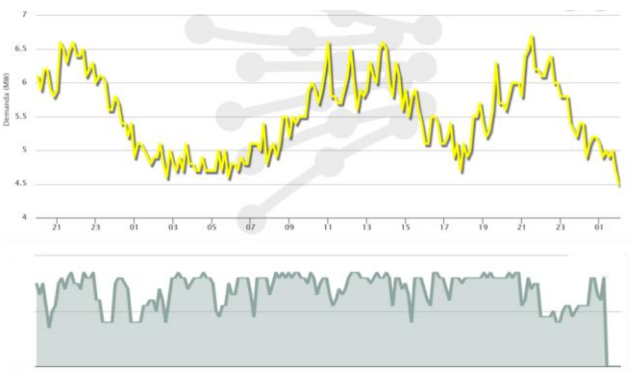

Fig.5. Graphs of changes in the load in the electrical network (yellow line) and the power of diesel generators (lower graph) in time during the day of August 19, 2018.

From these graphs it can be seen that the diesel engines in this project are not only used as a backup power source, but also provide load balancing of the entire system. For diesel power plants, this mode of operation is possible, although it is associated with additional energy losses. But atomic and large coal-fired power plants will not be able to provide this mode of operation.

In addition, during August 19, 2018, the average intensity of CO2 emissions to the atmosphere was slightly less than 1 ton per hour, although there was no need for this. These emissions to the atmosphere were made only because of the need to regulate the load in the electrical network.

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Zone 3 is characterized by a complete transition to fossil fuels. In this regard, it should be noted that internal combustion engines allow you to quickly respond to changes in the load on the electrical network, although this involves additional energy losses. However, diesel engines are significantly inferior in terms of the efficiency of using the initial fuel in combined-cycle plants. As a result, during the use of a backup energy source, diesel engines, CO2 emissions are significantly higher, which ultimately leads to a decrease in the total effect.

From the analysis of these three zones follows two main conclusions. First, hybrid power plants must be equipped with special efficient load balancing devices in the electrical network. Otherwise, this leads to fairly high energy losses and additional CO2 emissions into the atmosphere. Secondly, reserve sources of energy should have maximum efficiency of using the potential of fossil fuels.

We now turn to the analysis of all the main elements of the hybrid power station Gorona del Viento.

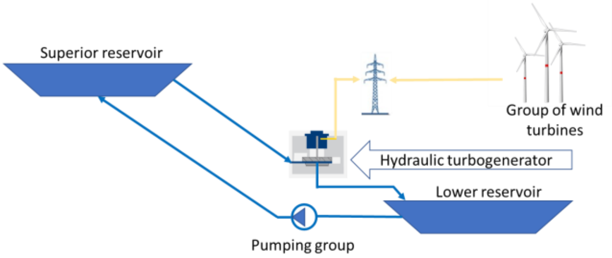

Fig. 6. The group of elements of the power station Gorona del Viento, using renewable energy sources.

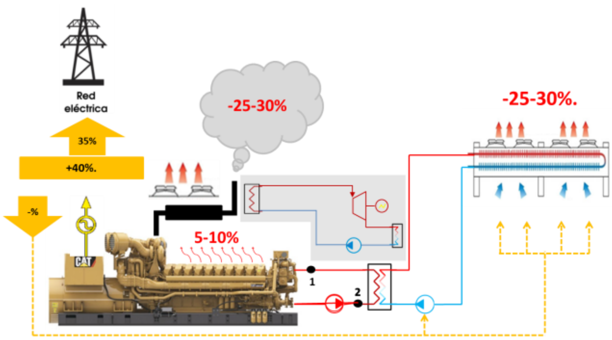

Fig. 7. The group of elements of the Gorona del Viento power station using traditional fossil fuels.

The first group of elements, which is presented in Fig. 6, is designed to convert wind energy into electrical energy, which is then fed to consumers. In case of excess of the received electric energy, it is used for pumping water from the lower reservoir to the upper reservoir. In the case of a lack of electrical energy, water is supplied from the upper reservoir to the hydraulic turbine, which provides for the production of additional energy. After the hydraulic turbine, the water is drained into the lower reservoir. Thereby, accumulation of excess electrical energy, which was previously obtained using a renewable source, is achieved.

At the moment we will not analyse the efficiency of conversion of wind energy into electrical energy. Of course, the efficiency of wind turbines existing today leaves much to be desired. But this is not the subject of research at the moment. In the future, this will be done. But in this work and at this stage of the research we will proceed immediately to the analysis of the pumped storage power plant.

Currently developed many different energy storage technology. The most common of these are hydro-accumulation and energy storage using compressed air and batteries. Each of these technologies has its own energy storage efficiency.

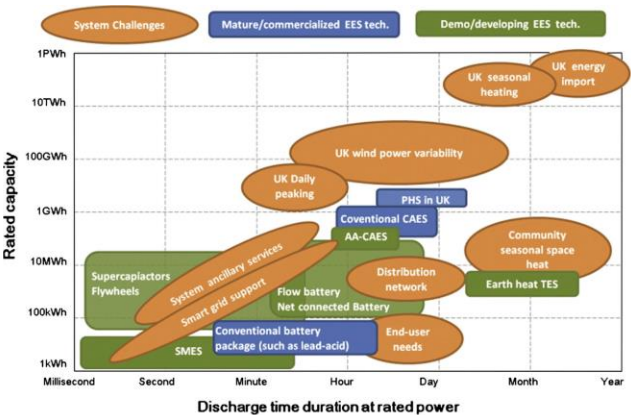

Fig. 8. Energy storage efficiency using various storage technologies [11].

From the operating experience of hydroaccumulating power plants and analysis of other authors' studies, it is possible for a paste to say that the loss of electric energy is up to 30 - 40% [8], [14], [15].. Thus, during each cycle of charging and discharging the accumulator, a certain percentage of electrical energy is lost, the value of which depends on the efficiency of the turbine, pumps and hydraulic losses in pipelines. The longer the length of the pipelines, the greater the loss of electrical energy. It should also be noted that this technology of hydroaccumulation is rather inertial, especially with a large length of pipelines and high water consumption. At the maximum power of the hydroelectric station Gorona del Viento, water consumption reaches 2 m3 per second. Such a mass of water is difficult to brake quickly.

At the same time, it should be noted that the technology of hydro-accumulation of electric energy is currently the most common in the world and the most reliable. Practically only this technology today allows accumulating large amounts of energy and storing it for quite a long time. As disadvantages of this technology, the high cost of construction, a rather high level of electric energy loss and inertia should be noted.

We now turn to the analysis of the second part of the Gorona del Viento power station, the scheme of which is shown in Fig.7. It is in this part that we have a large number of losses, and it is this part of the power station that generates a large amount of carbon dioxide emissions into the atmosphere.

To balance the load in the electrical network and to ensure peak loads, internal combustion engines or gas turbine installations are most often used. It is these types of heat engines that have the best maneuvering characteristics and relatively low capital costs. However, these types of heat engines have rather low efficiency indicators. Especially at partial loads. For comparison, Siemens combined-cycle power plant at rated load has an electrical efficiency of 62%.

This is precisely the paradox of hybrid power plants using renewable energy sources. Take, for example, two hybrid power plants. The structure of the first power station will include installation of a combined cycle on fossil fuel and an effective system of load control and energy storage. The second power plant will include a renewable energy source, an energy storage system and a backup gas turbine plant. The paradox is that the CO2 emissions into the atmosphere at these two power plants will be the same even if the share of the renewable energy source reaches 50%. The consumption of fossil fuels from these power plants will also be the same. The fact is that the first power plant operates continuously, but its efficiency in using the initial potential of fossil fuels is 62%, and the power and load control in the electrical network is carried out through an energy storage system. In the second case, the gas turbine plant operates only 50% of the time due to the use of renewable energy sources, but its efficiency in the use of fossil fuel is two times lower, a maximum of 31%. As a result, the consumption of fossil fuels and the intensity of CO2 emissions into the atmosphere remain the same. And if we add cogeneration technology to the first version of the power plant, it turns out that the reduction of real emissions of CO2 into the atmosphere will begin only when the share of the use of renewable energy sources reaches more than 75%. Today, the use of renewable energy can only reduce the operating time of power plants, which use outdated low-efficiency technologies for producing electric energy using fossil fuels. This, of course, has a positive effect on reducing CO2 emissions into the atmosphere, but the same effect can be achieved by increasing the efficiency of heat engines using fossil fuels.

From this it follows a very important conclusion that in the composition of hybrid power plants that use renewable energy sources, highly efficient backup energy sources should be used. Otherwise, even the short-term use of low-efficient backup energy sources can completely eliminate the positive effect on reducing CO2 emissions into the atmosphere. It is necessary to minimize as much as possible the energy losses of a backup source that uses fossil fuels for its work. Otherwise, in order to objectively estimate the share of using renewable energy sources in the overall balance of electricity production, a correction factor should be introduced that will take into account the degree of efficiency of the used backup source compared to the most modern energy generation technologies. According to the source [9]., the average efficiency of the Gorona del Viento diesel power plant is 38.2%. Consequently, the correction factor in comparison with the combined cycle plants of Siemens, which has an efficiency of 62%, will be 0.62.

We now return to the detailed analysis of the backup energy source of the Gorona del Viento power station, which includes seven Caterpillar engines with a capacity of 0.775 to 1.28 MW and three MAN engines with a capacity of 1.9 MW. In Fig. 7 shows the approximate figures of the thermal balance of diesel generators of electrical energy. It should be emphasized that the given loss percentages are given only for a qualitative analysis of the overall picture. For each particular engine, they may differ. If we take the initial thermal potential of the fuel as 100%, then the useful electric power that will be supplied to consumers through the electrical network will be in the case of using diesel engines no more than 40%. All the rest is losses and expenses of electric energy for own needs. The largest losses are losses with exhaust gases, losses with cooling water and losses inside the building from heated engine parts. In total, these losses amount to about 50% of the initial potential of the fuel. In addition, about 5% of the already received electrical energy is spent on the own needs of the power plant, namely, to drive the pumps and fans of the engine cooling system. Moreover, constant changes in engine power lead to additional losses, which range from 5 to 10%. Ultimately, when using such backup energy sources, the positive effect from the use of renewable energy sources is significantly lost.

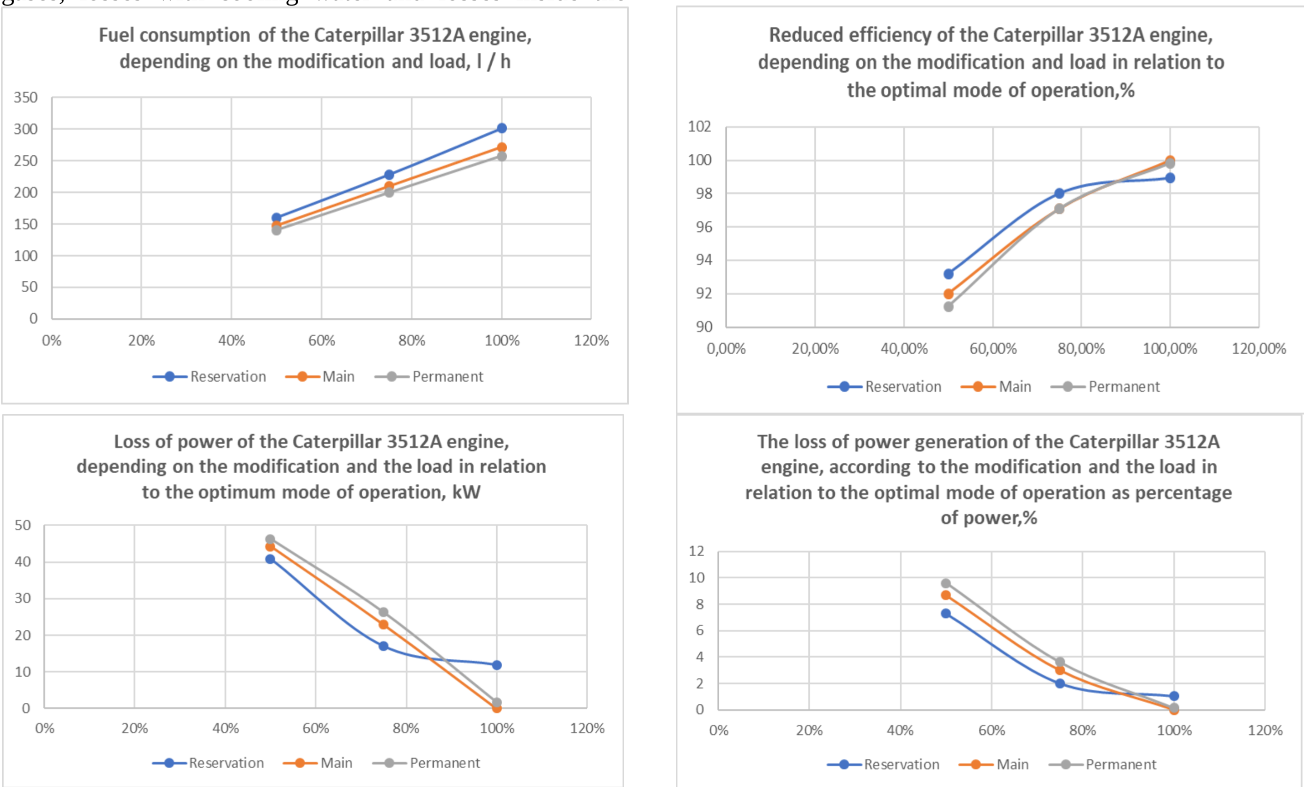

Fig.9. Energy losses when changing the load of diesel generators using the example of a Caterpillar 3512A engine (The data for calculations are taken from the technical documentation of the Caterpillar 3512A engine).

To some extent, these problems could be solved by using rechargeable batteries. However, today the most advanced batteries are quite expensive, especially for storing large amounts of energy. Experts believe that only by 2030 the cost of lithium-ion batteries will drop to $ 70 per 1 kWh. But even this price is unacceptable for the efficient operation of power plants. In addition, batteries will not ensure reliable operation of the power system.

As shown in the lower graph of Fig. 4, diesel engines continuously operate at variable loads. This ultimately leads to high losses. Especially if these changes in load is more than 75% of the rated motor power. In Fig. 9 shows the gravels of reducing the efficiency of a diesel generator depending on the modification and the load equation with respect to the nominal mode of operation.

3. Hybrid Hydroelectric Station Gorona del Viento (Analysis of the performance of the entire complex.)

The operating experience of the hybrid power plant Gorona del Viento allows a detailed analysis of the efficiency of the entire energy complex as a whole. Figures 4 and 5. show the work schedules of the main generators in the period from August 19 to August 22, 2018, as well as the schedule for the demand for electricity from consumers. In the first two days of the period under consideration, the island had a rather high wind speed, which made it possible for wind generators not only to fully satisfy all electrical energy needs, but also to accumulate a large amount of energy by pumping water into the upper reservoir. Then the wind speed began to fall and the lack of power generation was compensated by the hydroelectric power station and diesel generators. On the last day, the water supply was completely exhausted and the supply of electricity to consumers was made only by diesel generators.

As a result, during this period, wind generators provided the generation of 314 MWh of electrical energy, and with the help of a hydro turbine 30 MWh were additionally produced. Thus, using a renewable energy source, 344 MWh of electrical energy was generated, and the total consumption was 433 MWh. Diesel generators for the same period produced 199 MWh of electrical energy. Thus, if we proceed from the performance of wind turbines, the share of renewable energy sources will be 79%, and if we go from the reverse, from the performance

of diesel generators, the share of renewable energy sources in the total balance will be only 54%. The problem is that during this period the pumped storage system has a large negative balance. Electricity is spent on water injection more than returned. In general, the efficiency of the pumping system of the Gorona del Viento power station was less than 30%.
Such a low efficiency of the entire power plant as a whole is associated with sharp fluctuations in the load in the electrical network, which ultimately results in large energy losses.

4. Conclusion

1. The main objective of this study is to analyze the operating experience of the hybrid power plant Gorona del Viento as a whole and its individual elements. The data obtained as a result of this analysis allow us to outline the main ways to improve this project.
2. First of all, it should be stated that an increase in the number of wind generators or other installations using renewable energy sources as part of the Gorona del Viento power station is not appropriate at this stage in the implementation of this project. The higher the excess capacity of renewable energy sources, the higher the losses in the pumped storage system. As a result, this will lead to the fact that most of the electrical energy produced by additional wind turbines will be lost in the pumped storage system.
3. The technology of hydroaccumulation of energy has tremendous advantages over other currently existing energy storage technologies. However, this technology is rather inertial and has significant energy losses due to sharp fluctuations in the load in the electrical network, especially at high power. First of all, this applies to projects with a large length of pipelines for supplying water to the turbines.
4. To equalize the load fluctuations in the electrical network, it is advisable to create virtual power plants or a system of "smart" consumers on the island of El Hierro, which can be switched on and off depending on the specific situation in the electrical network. The introduction of this technology does not require significant financial costs, but will significantly increase the efficiency of the Gorona del Viento power station. Moreover, for the implementation of this project, subsidies can be used, which are currently allocated by the Island Government.
5. To equalize the operating modes of all generators of the Gorona del Viento power plant, it is advisable to use additional energy storage devices at the power plant itself, which would quickly and without significant expenses compensate for oscillations. At the same time, the power of these additional energy storage devices can be relatively small, within 1 MW, which will ensure a smooth transition of the main hydroelectric station from one power level to another.
6. A sufficiently large effect on reducing CO2 emissions into the atmosphere can be achieved using a utilization circuit of diesel generators. This will allow simultaneously solving several problems of the Gorona del Viento power station. First, it is to increase the efficiency and reduce the fuel consumption of diesel generators by 10-15%. Accordingly, this will reduce CO2 emissions into the atmosphere. Secondly, the turbo-generator of the utilization circuit will allow to quickly regulate the generation of the electrical load.

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