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Hydrogen technologies as a method of compensation for inequality of power generation by renewable energy sources

***Abstract**. The method and methods of reserving the instability of the generation of renewable energy sources (RES) in electric power systems (EPS) caused by weather conditions are analyzed. It is shown that these can be shunting power plants and various types of energy storage. Existing maneuvering capacities and hydrogen technologies with biogas plants are considered as a reserve for the development and increase of RES capacity in power systems. Attention is mainly paid to the problem of participation of photovoltaic power plants (PV plant) in balancing power and electricity in the power system. An algorithm for using hydrogen as an energy source to reduce the error between the actual and projected hourly schedules of PV plant generation in the balancing group is considered. Mathematical models are developed on the basis of similarity theory and criterion method. This approach, with the least available source information, provides an opportunity to compare different methods of redundancy of non-uniformity of PV plant generation, assess their proportionality, as well as determine the sensitivity of costs to the power of redundancy methods. Criteria models have been formed, which allow to build the dependences of the costs for redundancy of non-uniformity of power generation on the capacity of hydrogen-type storage devices and on the capacity of the system reserve together with the capacity of power transmission lines. It is shown that such dependencies make it possible to more reasonably choose certain methods of reservation in accordance with the characteristics and requirements of the EPS.*

***Streszczenie.** Przeanalizowano sposób i metody rezerwowania niestabilności wytwarzania odnawialnych źródeł energii (OZE) w systemach elektroenergetycznych (SEE) wywołanych warunkami atmosferycznymi. Wykazano, że mogą to być elektrownie manewrowe i różnego rodzaju magazyny energii. Istniejące zdolności manewrowe i technologie wodorowe wraz z biogazowniami traktowane są jako rezerwa dla rozwoju i zwiększenia mocy OZE w systemach elektroenergetycznych. Zwrócono uwagę przede wszystkim na problem udziału elektrowni fotowoltaicznych (elektrowni fotowoltaicznych) w bilansowaniu mocy i energii elektrycznej w systemie elektroenergetycznym. Rozważany jest algorytm wykorzystania wodoru jako źródła energii w celu zmniejszenia błędu pomiędzy rzeczywistymi i przewidywanymi harmonogramami godzinowymi wytwarzania elektrowni fotowoltaicznych w grupie bilansowej. Modele matematyczne tworzone są w oparciu o teorię podobieństwa i metodę kryteriów. Takie podejście, przy najmniej dostępnych informacjach źródłowych, daje możliwość porównania różnych metod redundancji niejednorodności generacji fotowoltaicznej, oceny ich proporcjonalności, a także określenia wrażliwości kosztów na moc metod redundancyjnych. Powstały modele kryterialne, które pozwalają na zbudowanie zależności kosztów redundancji niejednorodności wytwarzania energii od pojemności zasobników typu wodorowego oraz od pojemności rezerwy systemu wraz z przepustowością linii elektroenergetycznych. Wykazano, że takie zależności pozwalają na bardziej rozsądny dobór pewnych sposobów rezerwacji zgodnie z charakterystyką i wymaganiami systemów elektroenergetycznych. (**Technologie wodorowe jako metoda kompensacji nierówności wytwarzania energii przez odnawialne źródła energii**)*

Keywords: renewable energy sources, photovoltaic power plants, power system, instability of generation, redundancy, hydrogen technologies, similarity theory, criterion method..
Słowa kluczowe: odnawialne źródła energii, elektrownie fotowoltaiczne, system elektroenergetyczny, niestabilność generacji, redundancja, technologie wodorowe, teoria podobieństwa, metoda kryterium.

Introduction

The main types of renewable energy sources (RES), in particular wind and photovoltaic plants (WPPs and PVP), are characterized by periodicity in operation and changes in the magnitude of energy potential depending on the time of day and year. This inconsistency reduces the energy efficiency of sources, so the use of energy from renewable sources requires power, convenient for storage, transportation, and use. This may be hydrogen. The development of hydrogen energy involves the construction of an efficient and economical infrastructure for the supply of consumers with hydrogen - a universal environmentally friendly energy source. Hydrogen production for the purpose of energy storage and transportation is an effective solution to the problem of stable energy supply from renewable sources. Extensive use of hydrogen as a highly efficient and environmentally friendly energy source, as well as fuel cells capable of converting the chemical energy of hydrogen into electricity with minimal losses, in recent years is considered the most promising way to significantly reduce harmful emissions [1, 2].

As a result of a significant increase in the installed capacity of renewable energy sources, primarily wind and solar, there is a need to limit the supply of energy from renewable sources to the electricity system to balance demand and generation [3]. The use of renewable energy to supply entire sectors of the economy poses serious problems if not complemented by efficient energy storage systems. The use of hydrogen for intermediate storage of surplus electricity, creating both short-term and medium-term and long-term off-season energy reserves in renewable energy systems, helps to solve this problem [4-6].

Obtaining hydrogen by electrolytic decomposition of water using green electricity has zero carbon emissions, energy can be stored for long periods of time, serving as a necessary system buffer and ensuring the stability of energy systems. This allows the decarbonization of a wide range of end uses, providing clean generation and heat for transportation and stationary applications. Hydrogen in various states can be transported over long distances, which allows the distribution of energy both within the country of hydrogen production and between other countries.

Despite the advantages of hydrogen, hydrogen technologies have to compete on costs with other ways to compensate for irregularities and redundancy of electricity generation RES. These include electrochemical storage, biogas plants, storage power plants, as well as the system reserve of thermal power plants as a paid service [7, 8].

The aim of the article is to show the possibilities of hydrogen as an energy carrier in comparison with other ways to increase the energy efficiency of renewable energy sources during their operation, in particular to compensate for uneven electricity generation by photovoltaic power plants.

Improving the energy efficiency of RES during the balancing of the power system through the production and consumption of hydrogen as an energy source

In the process of RES operation, in particular PV power plants, the problem of balancing the consumption and generation of electricity, including all energy sources, is solved in the electric power system (EPS). For PV power plants the problem is formulated as

$$f = \frac{W_{pr} - W_{ac}}{W_{pr}} 100\% \to \min, \tag{1}$$

where W_{pr} is the value of the hourly projected electricity generation PV power plant for the next day; W_{ac} is actual PV power plant electricity generation for the same time T; f is forecast error, which should be less than the allowable (for PV power plant 5%).

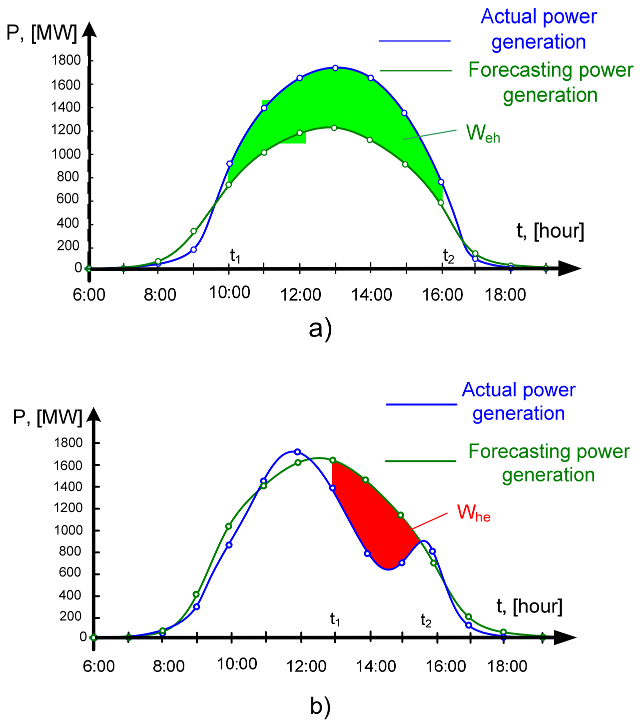

Fig. 1. Daily schedules of PV power generation in case of excess electricity generation (a) and in case of insufficient actual electricity generation (b)

For PV power plant, when they work in the balancing group to regulate the frequency and voltage in the power system, there are two interrelated tasks – the conversion of electricity into hydrogen and the use of hydrogen to generate electricity. In Fig. 1, and it is shown that the balancing group of the PV power plant produces more electricity than predicted and declared for the system operator. Some of the electricity (shown in green) is converted to hydrogen. In Fig. 1, b is projected to have more electricity than is actually produced by the PV power plant (shown in red) . To reduce penalties it is necessary that $W_{ac} \approx W_{pr}$. In this case, hydrogen is used to generate electricity and fulfill the condition $W_{ac} \approx W_{pr}$. Obviously, the excess hydrogen produced can be used for other purposes [6, 9].

The value of electricity that is produced more than required for the balance between generation and consumption and can be used for hydrogen production is defined as (Fig. 1, a)

$$W_{eh} = \int_{t_1}^{t_2} P_{ac}(t)\,dt - \int_{t_1}^{t_2} P_{pr}(t)\,dt \ , \tag{2}$$

where W_{eh} is the amount of electricity that must be consumed in order to meet the stated schedule of PV power plant generation (another option is to limit the actual generation, which is impractical for PV power plant owners and can be forced to sell only by the system operator to maintain the stability of EPS); t_1 and t_2 are the time when the hydrogen production and storage units are switched on and off.

The amount of electricity W_{he} (Fig. 1, b), which must be generated for the balance between generation and consumption and which can be produced by converting hydrogen into electricity, is defined as

$$W_{he} = \int_{t_1}^{t_2} P_{pr}(t)\,dt - \int_{t_1}^{t_2} P_{ac}(t)\,dt \ , \tag{3}$$

where t_1 and t_2 are the time when the installations for the use of hydrogen for the production of electricity by the balancing group (piston, gas turbine or steam-gas installations) are switched on and off.

Possible hydrogen technologies to increase the energy efficiency of RES during the balancing of the power system

In fig. 2 shows methods for producing hydrogen and Brown's mixture from electricity generated by RES and their application for electricity generation. Hydrogen generated with the participation of hydrogen is transferred to the general electricity supply system, but part of it is accounted for separately to form the balance of electricity in the EPS according to (3). It is advisable to involve biogas plants in the production of hydrogen from the electricity of PV power plants and WPPs for their full participation in balancing the state of the power system. This approach allows you to make full use of the available potential of RES to solve system-wide problems. However, this requires technical and economic coordination of ways to compensate for the uneven generation of electricity RES with a simultaneous increase in their energy efficiency. There is a need for a strategy of integrated use of PV power plants and WPPs and ways to compensate for their uneven generation of them, taking into account the requirements of the energy market. The technology of obtaining and accumulating hydrogen is decisive.

For evaluation, consider, as an example, the process of hydrogen production by electrolysis of water, which differs favorably from other methods by single-stage and relatively simple hardware and technological solutions. In addition, the main raw material, in this case, is water - the most accessible and almost inexhaustible source. The process of electrochemical decomposition of water using an alkaline solution is described by the following equations [10]:

(4) $2H_2O + 2e = H_2\uparrow + 2OH$, cathode process

(5) $4OH^- = O_2\uparrow + 2H_2O + 4e$ anode process

(6) $2H_2O = O_2\uparrow + 2H_2\uparrow$ total process

The total equation shows that the electrochemical decomposition of water releases hydrogen and oxygen in a ratio of 2:1. The obtained gases have a high degree of purity, the amount of impurities (oxygen in hydrogen and hydrogen in oxygen) does not exceed 0.1%. Electrolysis of water is used in industry, but the cost-effectiveness and competitiveness of the method depends on the availability of cheap electricity, the cost of which mainly depends on the cost-effectiveness of the process. Although such technology is currently industrially developed, but the complexity of the scale of this process.

For example, the feasibility study for the location and connection of hydrogen generation plants from electricity generated by PV power plants, transportation and conversion of hydrogen energy into electricity is considered separately. There are two possible approaches to the use of hydrogen technologies in the power system: conditionally local and system-wide. According to the first option, individual owners of PV power plants or united in balancing groups solve the problem of participation in the work of the power system independently (obviously, according to certain rules established by the power system). According to another option, the relatively large capacity of the hydrogen production unit and the methods of its use are centrally developed. According to this option, in the framework of the problem considered in this article, the participation of the PV power plants in balancing electricity is solved through paid services, which organize access to centralized sources of hydrogen and the results of its use.

Obviously, a combined approach is possible when both options are available. The implementation of locally centralized hydrogen production has certain advantages. Individual PV power plants and their consolidation into balancing groups can work autonomously, coordinating their work with the EPS.

Under this scheme, the production of hydrogen as a universal energy source is possible both in close proximity to the consumer, for example, from the gas station of electric vehicles on fuel cells (PCEVs), and in remote areas with significant energy potential RES with subsequent transportation of hydrogen to gas stations in special tanks or by pipeline. In addition, the hydrogen storage of energy from renewable sources makes it possible to create long-term off-season energy reserves, which is especially important when addressing the issue of stable energy supply.

If the option of installing hydrogen production plants centrally, ie for system-wide use, is implemented, the minimum total cost C_Σ is defined as

(7) $$C_\Sigma = C_h(P_h) + C_g(P_g) + C_{ps}(P_{ps}) + C_{tr}(P_{tr}) \to \min$$

Where $C_h(P_h)$ is the cost of obtaining hydrogen by electrolysis; $C_g(P_g)$ is costs associated with the use of biogas technologies; $C_{ps}(P_{ps})$ is costs of using the system reserve, which are the cost of maintaining the reserve at the TPP; $C_{tr}(P_{tr})$ is the cost of reserves of capacity of transmission lines, which is necessary for the transportation of electricity from/to the place of connection of reserve power to the power system;
P_h, P_g, P_{ps}, P_{tr} are respectively, the optimal values of power, which are determined from each of the ways to compensate for the uneven generation of electricity RES.

Optimization of PV power plant hydrogen production costs during balancing of EPS modes

Since the introduction of hydrogen technologies to reserve electricity generation RES in the power system will be carried out in stages, it is advisable to first consider the use of hydrogen at the PV power plant to reduce the error f in (1). According to the scenario that the power system to compensate for the instability of the generation of PV power plant uses the shunting power of the system and the installation of production and use of hydrogen, task (7) will be rewritten:

(8) $$C = C_h(P_h) + C_{ps}(P_{ps}) + C_{ts}(P_{ts}) \to \min .$$

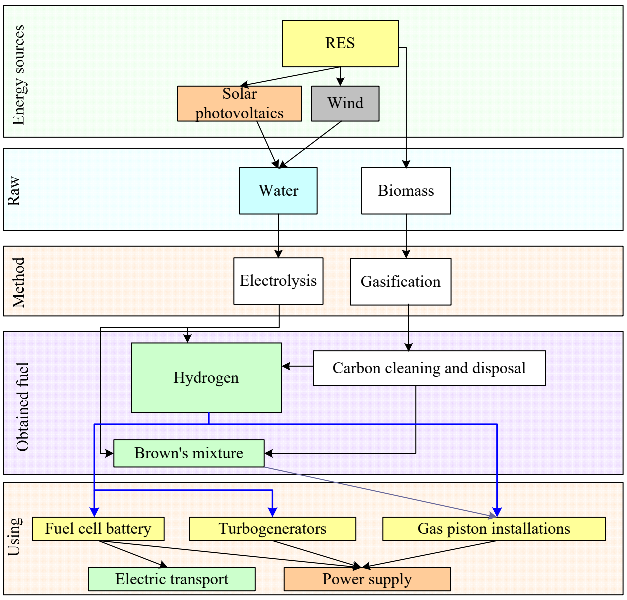

Fig. 2. Methods of obtaining hydrogen and Brown's mixture and their application

The cost of using the system reserve, which is actually compensation for the maintenance of the reserve for loading for TPP power units operating on price bids is determined by the formula [11]:

$$C_{ps} = \begin{cases} P_{ps} \cdot (c^C_{esh} - dc_{fuel}), c^C_{esh} \rangle dc_{fuel} \\ 0, c^C_{esh} \langle dc_{fuel} \end{cases} \quad \text{(r.u./h)},$$

where c^C_{esh} is the marginal price of the system, which is formed for the settlement hour on the wholesale electricity market, USD/kWh; dc_{fuel} is incremental price of fuel, which is determined on the basis of the derivative function of fuel consumption for electricity production by the level of load on the power plant unit and the cost of the required fuel.

Modified mathematical model of specific costs per 1 kW of redundancy according to the scenario, which assumes the use of hydrogen as energy storage and takes into account the features of the power system, which requires redundancy, can be represented as the equation

(9) $$C = \frac{K_1}{P_h} + K_2 P_{ps} + K_3 P_{tr} + K_4 \frac{P_h^2}{P_{ps}^2 \cdot P_{tr}}$$

where K$_1$, K$_2$, K$_3$, K$_4$ generalized constants containing the original data of the problem (primarily price indicators).

The first component of the equation takes into account the specific costs of the implementation of redundancy using the system of production and use of hydrogen as an energy storage; the second, third, fourth components take into account the cost of electrical networks.

To analyze the system of redundancy instability of RES generation, we use the methods of similarity theory, in particular the criterion method [12, 13]. The advantage of the chosen method is that it allows to obtain similarity criteria that link the same parameters, in our case different methods of redundancy, and create conditions for analyzing the proportionality and sensitivity of calculation results in relative units with limited source information [14].

Problem (10) corresponds to the condition of canonicity, when the measure of its complexity is s=m–n–1=0, where m is the number of members of the objective function, n is the number of variables Pi. According to the criterion method, we write a system of orthogonal and normalized (orthonormal) equations for (10) [13, 15]:

$$(11)\quad \begin{cases} -\pi_1+2\pi_4=0; \\ \pi_2-2\pi_4=0; \\ \pi_3-\pi_4=0; \\ \pi_1+\pi_2+\pi_3+\pi_4=1. \end{cases} \Rightarrow \begin{bmatrix} -1 & 0 & 0 & 2 \\ 0 & 1 & 0 & -2 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 1 & 1 \end{bmatrix} \times \begin{bmatrix} \pi_1 \\ \pi_2 \\ \pi_3 \\ \pi_4 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}.$$

Since for the problem of optimizing the methods of compensating for the instability of RES generation in the form (10) the degree of complexity is zero, the solution of this system of equations (11) is obtained simply:

$$\pi_1=\pi_2=2/6\,;\ \pi_3=\pi_4=1/6\,.$$

In accordance with the method of integral analogues [12] we write a system of equations in which the similarity criteria are related to the unknown Pi, taking into account (10) and the solutions of the system of equations (11):

$$(12)\quad \begin{cases} \pi_1=\dfrac{2}{6}=\dfrac{K_1}{C\,P_h}; \\ \pi_2=\dfrac{2}{6}=K_2\cdot P_{ps}/C; \\ \pi_3=\dfrac{1}{6}=K_3\cdot P_{tr}/C; \\ \pi_4=\dfrac{1}{6}=\dfrac{K_4\cdot P_h^2}{C\,P_{ps}^{-2}\cdot P_{tr}}. \end{cases}$$

From system of equations (12) are received optimal values of power units for redudancy instability power generation PV power plants:

$$(13)\quad P_h=\left(\frac{K_1^4}{4K_2^2\cdot K_3\cdot K_4}\right)^{\frac{1}{6}};\qquad P_{ps}=\left(\frac{4K_1^2\cdot K_3\cdot K_4}{K_2^4}\right)^{\frac{1}{6}};$$

$$P_{tr}=\left(\frac{K_1^2K_2^2K_4}{16K_2^5}\right)^{\frac{1}{6}};\ C=3\left(4\cdot K_1^2\cdot K_2^2\cdot K_3\cdot K_4\right)^{\frac{1}{6}}.$$

In criterion form equation (10) is presented

$$(14)\quad C_*=\frac{\pi_1}{P_{h*}}+\pi_2P_{ps*}+\pi_3P_{tr*}+\pi_4\frac{P_{h*}^2}{P_{ps*}^2\cdot P_{tr*}},$$

where $C_*=C/C_{\min}$; $P_{h*}=P_h/P_{h\,o}$, $P_{ps*}=P_{ps}/P_{ps\,o}$, $P_{tr*}=P_{tr}/P_{tr\,o}$, where P_h, P_{ps}, P_{tr} are actual and optimal values power for every redudancy methodologies.

With take into account numeric values of similarity criterions (14) rewrite:

$$(15)\quad C_*=\frac{1}{3P_{h*}}+\frac{P_{ps*}}{3}+\frac{P_{tr*}}{6}+\frac{P_{h*}^2}{6P_{ps*}^2\cdot P_{tr*}}.$$

Separate the component of the cost of redundancy through the use of hydrogen (the first member) and the component that characterizes the cost of using the system reserve and the cost of increasing the margin of capacity of transmission lines (second member):

$$(16)\quad \begin{aligned} C_*&=0{,}333\cdot P_{h*}^{-1}+ \\ &+0{,}667\cdot\begin{pmatrix} 0{,}5\cdot P_{ps*}+0{,}25\cdot P_{tr*}+ \\ +0{,}25\cdot P_{h*}^2\cdot P_{ps*}^{-2}\cdot P_{tr*} \end{pmatrix}. \end{aligned}$$

According to the adopted model (16), the costs C to compensate for the unevenness of the schedule of PV power plant generation by redundancy will be economically feasible if 2/3 of these costs are used for network upgrades and system reserve use, and 1/3 of redundancy costs for storage and use of hydrogen energy.

Economically feasible values of similarity criteria do not depend on K$_1$,…, K$_4$ and determine the proportionality of the model, ie the share of variable costs attributable to the elements of the reserve system for instability of PV power plant generation. As for the generalized indicators K$_1$,…, K$_4$, their impact on economically feasible values of capacity $P_{eh*}, P_{eps*}, P_{etl*}$ and costs can be estimated by writing (13) as follows:

$$(17)\quad P_{eh*}=\left(\frac{K_{1*}^4}{4K_{2*}^2K_{3*}K_{4*}}\right)^{\frac{1}{6}};\ P_{eps*}=\left(\frac{4K_{1*}^2K_{3*}K_{4*}}{K_{2*}^4}\right)^{\frac{1}{6}};$$

$$C_*=3\left(4K_{1*}^2K_{2*}^2K_{3*}K_{4*}\right)^{\frac{1}{6}}.$$

where $K_{i*}=\dfrac{K_i}{K_{ib}},\ i=\overline{1,4}$; K_{ib} are basic values of cost indicators.

Оскільки, як правило, на етапі проектування точні значення показників K$_i$ невідомі, але відомим є їх діапазон $K_{i\min}-K_{i\max}$, то за базисне значення варто приймати середнє значення діапазону цін [16].

Since, as a rule, at the design stage the exact values of Ki are unknown, but their range $K_{i\min}-K_{i\max}$ is known, the base value should be taken as the average value of the price range [16].

From the received expressions it is possible to estimate influence of change, for example, on economically expedient values of all variables. Expressions (17) show that the economically feasible values of capacity, which are determined from each of the methods of reservation and the cost of their implementation, depend on the accepted scenario of the implementation of the reservation. Therefore, economically feasible methods of redundancy and their capacity, as well as the parameters of each method are selected taking into account their interaction in the system. Expression (16) also allows us to estimate the impact of the source data on the economically feasible values of costs and capacity, which are determined from each of the methods of redundancy, ie to investigate the sensitivity of costs to changes in capacity.

This analysis allows us to conclude that the cost allocation for the backup scenario under study is more sensitive to the choice of hydrogen storage capacity and the choice of system reserve capacity. In fig. Figure 3 presents an analysis of the sensitivity of specific costs in relative units and as a percentage of changes in one of the influencing factors with constant others, the costs are determined by formulas (16) and (17).

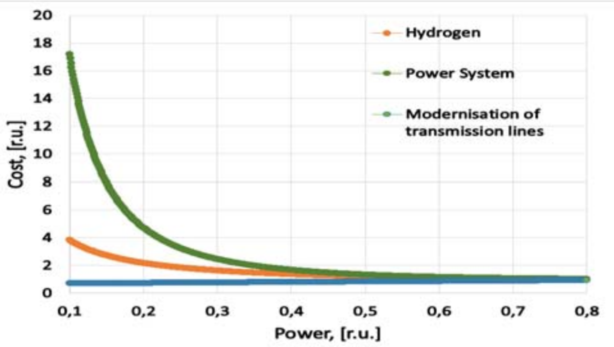

Fig. 3. Cost sensitivity: to changes in the capacity of hydrogen storage (green curve), to changes in the capacity of the system reserve (orange curve) and to changes in the capacity of transmission lines (blue curve)

Example

For the case shown in Fig. 1a and 1b, determine the value of the difference between the projected and actual electricity generation by the balancing group of the PV power plant, which must be compensated in the problem of balancing the EPS regime.

For the case shown in Fig. 1a, we approximate the graphs of the actual and projected capacity of the PV power plant:

(18) $P_{ac} = –98,81t^2 + 2556,2t – 14769$ (MW),
(19) $P_{pr} = –57,857t^2 + 1476,4t – 8220$ (MW).

According to (2), the amount of electricity produced in excess of the required balance and which can be used for hydrogen production is defined as the area bounded by curves (18) and (19):

$$W_{eh} = \int_{10}^{16} -40,953t^2 + 1079,8t - 6549)dt = 2667\ (MW \cdot h)\ .$$

For the case shown in Fig. 1b, we approximate the graphs of the actual and projected capacity of the PV power plants:

(20) $P_{ac} = 264,57t^2 –7736,9t+57249$ (MW),
(21) $P_{pr} =–148,29t^2 + 3922,4t–24278$ (MW).

According to (3), the amount of electricity, the production of which is insufficient to the required balance and which can be produced from hydrogen, is defined as the area bounded by curves (20) and (21):

$$W_{he} = \int_{13}^{15,5} (-412,86t^2 + 11659,3t - 81527)dt = 1417(MW \cdot h)$$

To calculate the potentially possible production of green hydrogen by electrolysis, we assume that 4,5 kWh of electricity is provided per 1 m^3 of hydrogen or 50,56 kWh per 1 kg of hydrogen [17]. For hydrogen production you can spend 2667 MWh, ie it is M = 2667 · 103 / 50,56 = 53380 kg of hydrogen.

This amount of hydrogen is converted into the energy of fuel cells. Using an online fuel cell calculator [18], we determine that when burning hydrogen from 53380 kg of hydrogen, 1423,154 MWh of electricity can be obtained.

Another approach to the use of hydrogen is to use it as a component of the mixture for TPP turbogenerators. For example, consider a turbine [19]. A mixture of 25% hydrogen and 75% gas is used. To ensure the operation of the LM 9000 turbine in the nominal mode of 73,5 MW requires 978 kg of hydrogen per hour or 978x2,5 = 2445 kg per 2.5 hours. 1417 / (73,5x2,5) = 8 turbines must be used to generate 1417 MWh required for balancing. Their work consumes 8x2445 = 19560 kg of hydrogen. In addition, if the installation is configured with a combined cycle of 2x1, then to reduce CO_2 emissions at a price of $ 0,17. The USA saves $ 2,900 per tonne of CO_2.

Conclusions

To increase the energy efficiency of power plants that use renewable energy, in particular solar energy, and which operate in the EPS in parallel with other power plants, there is a problem with forecasting the schedules of their electricity generation. Due to their natural uneven generation and increasing their share in the country's electricity balance, in order to ensure the reliability of the EPS, requirements are formulated for the accuracy of the declared hourly schedules of PV power plant generation. To compensate for the uneven generation of PV power plants in the power system, a corresponding power reserve is formed. One of the effective ways to reserve energy can be hydrogen, which is obtained by electrolysis using electricity PV power plants. Hydrogen obtained in other ways, for example from biomass, can be used to generate electricity by appropriate installations.

An algorithm for ensuring a given accuracy of coincidence of the actual and projected graphs of electricity generation of PV power plants using hydrogen technologies is proposed. The algorithm is built in such a way that when at a certain time interval the actual value of generation exceeds the forecast, the system of formation and storage of hydrogen is started. Conversely, when the actual value of generation is less than the forecast, the accumulated hydrogen is triggered by plants that generate electricity. This algorithm should be used for centralized power control in the balancing group of the PV power plants.

If the EPS has a free reserve of power that can be used by the balancing group of the PV power plants as a paid service, it is advisable to consider the option of its use. In this case, to compensate for the instability of the generation of PV power plants, the shunting power of the system and the installation of production and use of hydrogen are used. A method for optimizing the reserve power of the power system to compensate for the uneven generation of PV power plants is proposed. The criterion method based on the theory of similarity allows you to choose the best option for a limited amount of information. The optimization results are obtained in such a way that allows to analyze the proportionality and sensitivity of the component costs for ways to compensate for the uneven generation of PV power plants. The results of proportionality make it possible to rank the ways to compensate for the uneven generation of PV power plants at cost, and the sensitivity - rationally, most efficiently use the power of different methods during operation.

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