Modes and technological features of electrolysis consumers of electricity

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Abstract. The article analyzes the use of direct voltage and current for electrolysis consumers powered by valve controlled converters, generating higher harmonics into the network, consuming reactive power fr0om the network and significantly affecting the quality of electricity and the efficiency of the entire power supply system.

1 Introduction

At present, the issue of rationalizing production, improving product quality, saving material and labor resources is of great importance. In the field of energy, this is characterized by specific figures for saving fuel, electricity and other material resources in economic development plans [1-5, 10, 8, 6].

Significant reserves of fuel savings - energy resources are available in electrical networks where electricity is transmitted according to complex schemes, undergoes multiple transformations, and in order to ensure its required parameters, it is necessary to systematically correct the scheme, equipment composition and mode by available controls using various characteristics (statistical, economic) of the system power supply and consumers of load nodes.

Therefore, the determination of the optimal level of voltage in the supply network is important and should be carried out on the basis of studying the patterns of changes in the productivity of electrolysis plants, the consumption of raw materials and materials, and the total loss of power and energy [6-12, 16, 17, 20].

All these factors are jointly displayed in the economic characteristics of the object. The economic effect caused by the improvement in voltage quality for electrolysis plants with a continuous technological process can be determined analytically.

An analysis of the individual components of the economic characteristics shows that the components of the output and the specific consumption of electrical energy have a very significant impact [18, 19, 13-15, 5].

2 The current state of the investigated problem

Due to the positive features of direct current consumers (electrolysis baths, electrified transport, etc.), they are increasingly being used in various areas of the national economy. Constant voltage and current for supplying such consumers from controlled valve converters with good technical and economic characteristics. These converters have two existing disadvantages, which are the generation of higher harmonics into the network and the consumption of reactive power from the network. Although appropriate measures are taken to eliminate these shortcomings, the actual values of these harmonics and reactive power vary widely and significantly affect the quality of power and the efficiency of the entire power supply system. Therefore, the analysis of these phenomena on the example of specific powerful consumers is of great importance. Given the wide variety of such consumers, we will consider the issues of power quality in rather energy-intensive installations for the production of chlorine and naustic soda [21-25, 7, 11, 14].

The block diagram of the main processes for the production of products is shown in Figure 1. In the electrolysis shop, two series of vank are installed, equipped with 125-135 baths in each series with a rated current of 25 kA and a voltage of 425 V. Each series of baths is powered by two converter units installed at the substation. In normal mode, each unit individually provides the current load of the series. However, to improve the reliability of the power supply of the electrolysis plant, both units are in operation. Under the action of a direct current passing through an aqueous solution of $NaCI_2$, the movement of $Na^+ \ and \ CI$ ions occurs, and chlorine is released at the anode, and caustic sodium and hydrogen are released at the cathode:

$$2NaCI + 2H_2O = CI_2 + 2NaOH + H_2.$$

With such a clean electrolysis process, the current efficiency of the whole products will be 100%.

Electrolysis is accompanied by complex processes on the surface of the electrodes - a double electric layer that

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appears at the electrode-solution interface and electrokinetic processes in them, depending on the operating mode of the installation. The double electric layer is an elementary capacitor with a sufficiently large active conductivity and capacitance. The higher harmonics of the currents in these capacitors significantly affect the electrode processes and, with their optimal value, can improve the weight of the complex processes and increase the current output of the installation. The electrical parameters for electrode capacitors vary depending on the value and frequency of the current of higher harmonics. The reactive component of these resistances can be either capacitive or inductive. Thus, the presence of an alternating component in the anode current leads to a violation of the stationarity of electrolysis processes and an improvement in the performance of the installation. Therefore, the determination (synthesis) of the parameters of the equivalent circuit of the electrolysis bath and the analysis on their basis of the optimal values and frequencies of the higher harmonic currents are essential [21, 26-31, 14, 10].

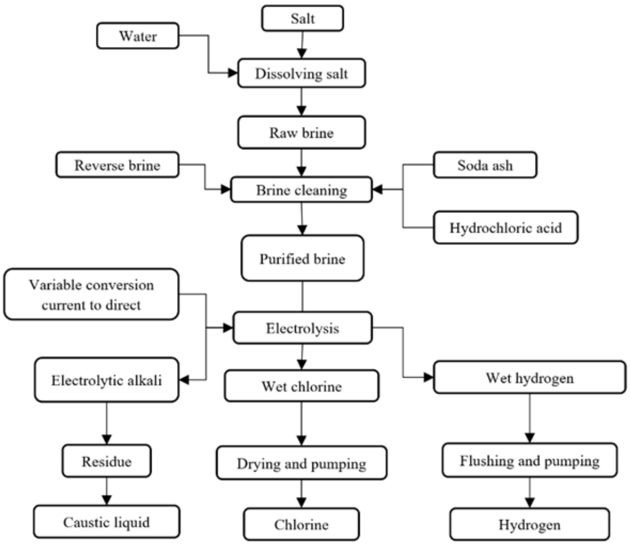

Fig 1. Structural diagram of the main processes of production of products [32]

The electrolysis process is characterized by indicators:

a) current output coefficient, %,

$$\eta = \frac{P_a}{P_t}, \tag{1}$$

where P_a and P_t are the theoretically possible and actually obtained amount of the *NaOH* product:

$$P_a = VC_{NaOH}, \tag{2}$$
$$P_t = Itk; \tag{3}$$

here V is the volume of the obtained electrolytic alkali, l; C_{NaOH} alkali concentration, g/l; I is the average current load on the bath, kA; t is the duration of the bath, h; k electrochemical equivalent (for *NaOH* k=1.492 g, for CI_2 k=1.323g);

b) The consumption of electrical energy per one received product

$$\beta = \frac{E_a}{P_a}; \tag{4}$$

c) Coefficient of use of electrical energy

$$\mu = \frac{W_u}{W_a}; \tag{5}$$

where W_a and W_u are actually and useful breakfast electric energy:

$$W_u = ItU_T\frac{\eta}{100}, \tag{6}$$
$$W_a = ItU_B; \tag{7}$$

here $U_t = 2.18$ V is the theoretical *NaCl* decomposition voltage; U_b is the actual voltage at the bath terminals, V.

Expression (5), taking into account (6) and (7), can be written as follows:

$$\mu = \frac{2.17\eta}{U_b 100}; \tag{8}$$

Consequently, the main technical and economic indicators of cold production (P_a, β, μ) are determined by the current output, voltage and load current of electrolysis plants.

The voltage balance at the cell terminals is characterized by the following equation:

$$U_\text{H} = E_a + E_c + \Delta U_a + \Delta U_e + \Delta U_d + \Delta U_c \tag{9}$$

where E_a, E_c are the anode and cathode potentials, $\Delta U_a, \Delta U_e, \Delta U_d$ are the voltage drop in the anode, electrolyte and diaphragm, respectively, V. ΔU_c is the voltage drop in the cathode, conductive elements and contacts, V.

Theoretically, the anodic chlorine evolution potential is 1.3595 V (at 18°C). The overvoltage of chlorine evolution under operating conditions varies within 0.11-0.16 V.

The cathode potential under production conditions at a temperature of 80 - 85°C is 1.0-1.06 V. The cathode overvoltage, regardless of the material, varies within 0.25-0.39 V.

The increase in voltage in the electrolyte $\Delta U_\text{Э}$ depends on the interelectrode distance and the electrical conductivity of the electrolyte, which is determined by its composition and gas content temperature [13, 16].

To ensure a minimum voltage drop in the electrolyte, electrolysis should be carried out at a higher temperature (92±3) °C and a brine concentration of 310-315 g/l.

In the process of electrolysis, the voltage of the electrolyzer depends on the parameters of the installation mode and on the voltage level of the supply substation.

$$U_b = f(I, U, C_{NaCl}, C_{NaON}, t); \qquad (10)$$

Therefore, when optimizing the operating modes of the installation, along with technological parameters, it is necessary to take into account a significant stress factor.

The importance of such accounting is determined by the high energy intensity of the installations - up to 40% of the cost of production falls on the share of electricity and therefore the effect of voltage changes is significant.

Specific electricity consumption is 2685-2813 kWt·h/t. A change in the voltage and internal resistance of the baths leads to the fact that the current of the installation varies within a fairly wide range (about 15% of the rated current – 25 kA). Such a change has a bad effect on the productivity and technical and economic performance of the installations. To the greatest extent, current changes are caused by voltage changes in the 35 kV supply network. Influenced by the ripple of the rectified voltage and current. Therefore, when optimizing the installation mode, it is important to investigate the quality of AC and DC voltage [9, 26].

The converter units use a twelve-phase rectification scheme.

For this, the secondary winding of the supply transformer is split into four parts. Two secondary windings are connected in a star, and the other two in a delta. As a result, the phase vectors of the EMF of the secondary windings are shifted by 30°. The valves are connected in a three-phase bridge and give a rectified current of 6250 A. The rectified voltage is regulated in steps by changing the transformation ratio under load. A smooth change in voltage within the control stage is performed using a saturation choke with adjustable inductance [28, 21].

The joint operation of the two units provides compensation for the fifth and seventh harmonic currents in the supply network, provided that they are evenly loaded. Separate work creates the distribution of higher harmonics of this order along the supply lines and transformer, causing significant numbers in them.

The average value of the rectified voltage of the converter.

$$U_{do} = \frac{m}{\pi} U_m \sin\frac{\pi}{m}, \qquad (11)$$

Amplitude value of k-y harmonic U_{mk}

$$U_{mk} = \frac{m}{\pi} \int_{-\frac{\pi}{m}}^{\frac{\pi}{m}} U_m \cos\omega t \cos km\omega t d\omega l = \\ = \frac{m}{\pi} \sin\frac{\pi}{m} U_m \frac{2}{(km)^2 - 1} = \\ = U_{do} \frac{2}{(km)^2 - 1}; \qquad (12)$$

Frequency spectrum of the harmonic series

$$f_k = kmf, \qquad (13)$$

where f is the frequency of the mains voltage; m is the number of secondary phases; k is the multiplicity factor *(k=1,2,3……n)*.

Effective value ripple voltage

$$U_d = \sqrt{U_{do}^2 + U_{dV}^2}, \qquad (14)$$

where U_{dV} is the effective value of the variable component of the rectified voltage V.

Relationship

$$\left.\begin{aligned} k_n &= \frac{U_{dV}}{U_d} = \frac{\sqrt{\sum_{k=1}^{n} U}}{U_d} 100\% \\ k_{nk} &= \frac{U_{mk}}{U_{do}} = \frac{2}{(km)^2 - 1} \end{aligned}\right\} \qquad (15)$$

The values of the coefficients k_n and k_{nk} characterize the quality of the rectified voltage for 6 and 12 phase rectification circuits and the load mode of the operating installation are given below [9, 14]:

Table 1. These harmonics in the rectified voltage give rise to their corresponding current harmonics in the purpose of the electrolyzers.

Phases, m	6	12
	1,6	0,8
k_n, to at frequency, Hz		
100	-	0,003
300	0,0135	0,0135
600	0,0156	0,0079
900	0,0095	-

The voltage on the buses of 35 kV station varies within 36.5 - 38 kV. The voltage level changes 2-4 times a day. The duration of one or another voltage level is from 1 to 8 hours. Most of the time, the voltage on the RU35 kV buses is 38 and 37 kV.

With this voltage mode on the 35 kV buses of the station, the voltage level at other substations of the power center satisfies the established standards.

However, for electrolysis energy consumers located near the station, such a voltage regime does not meet the requirements of GOST and it is necessary to have automatic control devices in the power supply circuit of the plant [11].

To regulate and control the voltage on the AC and DC buses, a set of control devices is provided in the power supply circuit.

3 Conclusion

1. As it was shown, a change in the load current of a series of electrolyzers with a voltage deviation in the supply network significantly affects the technical and economic performance of the installations. Therefore, the determination of the optimal level of voltage in the supply network is important and should be carried out on the basis of studying the patterns of changes in the productivity of electrolysis plants, the consumption of

raw materials and materials, and the total loss of power and energy.

2. The actual voltage level on the 35 kV buses of the converting substation varies within 37–38 kV, which is close to the optimal value. The load current of the series varies within 21 - 29 kA, its average value for the controlled period is 24.2 kA and does not correspond to the optimal value. Such a change in the load mode of electrolyzers is caused both by voltage deviations in the network and by changes in the electrochemical and technological parameters of the electrolysis plant. Therefore, the determining factor in optimizing the operating mode of the electrolysis plant is the load current. The implementation of automatic response of the load current and maintaining it within the limits close to optimal, in the existing mode, a voltage of 35 kV provides the best technical and economic indicators of the technological process for the production of chlorine and naustic soda.

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