Valve converter with steeply falling external characteristics

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Abstract. This article discusses the development of three-phase valve converters with a steeply external characteristic consisting of a parametric current source, to the outputs of which three-phase valve kits are connected. A parametric current source, made according to the “star” scheme, converts the initial three-phase EMF system into a three-phase current system; the resonant circuit of the parametric source improves the energy performance of the valve converter, it contributes to the growth of energy efficiency indicators. Three-phase converters with a steeply falling external characteristic are most appropriate in practice when using them as power sources for energy-intensive consumers of electrical technology, which, ultimately, leads to an increase in the quality of products.

1. Introduction
One of the most characteristic features of the current stage is the ever-increasing growth of technical requirements for sources and converters of electrical energy in terms of reliability and economy. Almost half of the electricity produced is consumed in the form of direct current or non-standard frequency current [1, 2]. In this case, most of the electrical energy conversion is performed by semiconductor valve converters (VC). Valve converters closely deal with the development of electric power industry and electromechanics. The complexity of the processes in energy systems required the widespread introduction of new, efficient circuit design solutions for the VC, based on the latest achievements of science and technology. Semiconductor converters (SC) are one of the main load elements of networks, their work significantly determines the mode of operation of networks [3]. Valve converters are one of the main nodes of many power sources. The most energy-intensive consumers of electrical energy are consumers of electronic technologies, which are arc furnaces, electrolysis of non-ferrous metals, etc. [4, 5]. For electrical installations, the most efficient power sources are valve converters with a steeply dipping external characteristic or converters with characteristics of current sources, providing a significant improvement in many technological indicators of the production process [6]. Existing current transducers have a low power factor (cosφ), especially with deep regulation [7, 8]. Since the use of valve devices impairs the quality of electrical energy, the development of reliable current converters is an important and urgent task. One of the ways to solve the problem is the use of current-parameter converters (CPC), having a high power factor close to unity. The CPC forms a new class of converters—a class of current converters. A new class of circuits required a new approach to analyzing the operation of a current converter (single-phase, multi-phase) for various types of loads.
2. Analysis of the work of current transformers for different types of loads

2.1. Active load (contact heating)
One of the types of active load of the converter valve is industrial contact heating, which is one of the methods of direct heating. Direct heating provides: increase in labor productivity; reduction of technological losses, increase the service life of production equipment, etc. The advantage of contact heating is the high rate of metal heating. However, industrial installations of contact heating have low energy indicators (efficiency, cosφ). In addition, there is no possibility of smooth control of the load current, without the use of additional auxiliary devices [9–11].

2.2. Active - inductive load (arc furnaces)
Arc furnaces are powerful consumers with low power factor (cosφ ≈ 0.7 ÷ 0.8). The technological mode of arc furnaces is characterized by frequent technological short circuits. Part of the arc furnaces, which include vacuum arc furnaces, operates on direct current. In this case, the furnace power source must contain an AC-DC converter. Vacuum arc furnaces are sensitive to mode changes. Therefore, there is an urgent need to stabilize the operating current of the furnaces and the possibility of programmatically controlling the technological current of the furnace [12, 13].

2.3. Load in the form of counter-emf
Industrial electrolysis cells are the load in the form of counter-emf. Their volt-ampere characteristics (VAC) have a slight slope in the working area. The small slope of the VAC causes the need for automatic stabilization of the load current. This is due to the fact that fluctuations in the voltage of the network can lead to a significant change in the value of the technological mode of operation of the electrolyzers [14–16].

3. Three-phase CPC for various types of loads
Three-phase circuits of the CPC are used to supply powerful consumers. At the same time, the ripple of the current in the load is noticeably reduced, the heating intensity is increased due to an increase in the average value of the rectified current. The bridge circuit of the converter found the broadest application in powerful consumers with output voltages over one hundred and fifty volts. So, for example, when using a bridge circuit to power cells, as calculations show, the cost of a transformer is reduced by 12.5% in comparison with a six-phase zero circuit, the power factor rises by 0.01–0.05 [7].

3.1. Three-phase CPC for the active load
The circuit of one of the variants of a three-phase diode-thyristor CPC assembled by the bridge circuit and its time diagrams of operation is shown in Figure 1 and Figure 2. In the interval $t_0 - t_2$ of diodes 1–6, an uncontrolled bridge is conducted in a cyclic mode: 5 6 1–6 1 2–1 2 3 etc. In this case, the positive load current mode is realized in the output circuit of the converter. An additional controllable set assembled on thyristors $1'$, $3'$, $5'$ is introduced into the circuit to generate the load current. A control pulse is applied to the thyristor $1'$ of the additional gated set and the load current drops to zero at time $t_2$. The parametric current source is in short-circuit mode, which is provided by simultaneously operating gates of an uncontrolled bridge and an additional gated set. In order to control the pause in the load current, after the thyristor $1'$, the gate $3'$ of the additional gated set is turned on after two cycles, etc. When the pause formation is complete (moment $t_2$, Figure 2), the gate pulses are not generated by thyristors of the additional gated set, and the positive load current mode is restored in the load (only uncontrolled diodes 1–6 operates).
3.2. *Three-phase CPC for active-inductive load*
Current sources having steeply dipping external characteristics and providing high energy parameters (power factor, efficiency, etc.) are needed to supply arc furnaces. These requirements are fully met by three-phase current-to-voltage converters (CPC) with a natural current characteristic.

3.3. *Three-phase CPC for loads in the form of counter-emf*

The time diagrams of the load current of a three-phase current-measuring converter when operating on a counter-emf in the modes $I_{H} = +$ and $I_{H} = 0$ are shown in Figure 2b. The $I_{H} = 0$ mode for $Z_{H} = E_{d}$ is not typical for the CPC and given only for qualitative analysis in Figure 2b. A detailed analysis of the operation of single-phase and three-phase CPC when operating on the counter-emf was carried out in [7].

The implantation of current parametric converters for a series of non-ferrous metal electrolyzers allows stabilizing the current of the load (at the least by 1%) due to the resonance circuit of the parametric source.
The technical and economic comparison of converter substations intended for aluminum electrolyzers with the use of power units such as VAK, VAKEL, etc., controlled by saturation inductors, and current-to-voltage converters has shown: the use of the CPC yields an economic effect, due to increase the current output, with approximately the same capital costs and power losses [7].

4. Conclusion
The acceleration of the scientific and technical process imposes ever-increasing demands on sources and converters of electrical energy in terms of reliability and efficiency. The most energy-intensive consumers are consumers of electrical technology (arc furnaces, electrolysis of non-ferrous metals, etc.). As power sources of energy-intensive consumers, semiconductor converters with characteristics of current sources are widely used. The use of current sources allows for stabilization of the operating current, improves many indicators of the process [6].

Existing semiconductor converters (SC) with the characteristics of current sources, along with significant advantages, have a low power factor, especially with deep regulation. Since the main elements of the SC are thyristors, having a non-linear volt-ampere characteristic, this leads to a deterioration in the quality of electricity in industrial power grids. Therefore, the development and analysis of current converters is an important and urgent task.

One of the ways to solve the problem for powerful consumers is the use of valve converters with steeply falling external characteristic, called current-parameter converters (CPC).

The current-parameter converter has a natural current characteristic and is a parametric current source to the output of which valve kits are connected. The CPC allows using the latitudinal methods to smoothly adjust the output load current, which is confirmed by the time diagrams of their work given in the article. The CPC is a new class of valve converters – a class of current converters. The new class of converters required a new analysis of the work with various types of plug-in loads. The valve converters with a steeply falling external characteristic considered in the article can be used for the practical design of secondary power sources of powerful consumers of electrical energy.

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