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Current converters with improved power characteristics

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Abstract. This article discusses development issue of semiconductor converters with the natural current external characteristics. The converter consists from a parametric current source, to the outputs of which are connected gated sets. The parametric source is a resonant circuit, which transforming electromotive force input system to the output system of currents. Here the resonant circuit in the current source provides an improvement in the power characteristics of the converter, so increasing energy efficiency indicators. This current converters use for supply most energy-intensive consumers with a steeply falling external characteristic (arc furnaces, electrolysis plants of non-ferrous metals, etc.), and also in electric drives with erection torque motor.

1. Introduction

Modern industrial production places ever increasing demands on sources and converters of electrical energy by reliability and cost. Electric energy is produced and distributed by alternating current at frequency of 50 Hz. At the same time more than 30 % of electricity is consumed at direct current [1]. The direct current is obtained by the conversion of alternating current by semiconductor converters. The power source for energy-intensive consumers (electrothermy, electrolysis plants of non-ferrous metals) is widely used by semiconductor converters with characteristics of current sources. For example, the current source for electrothermal plants allows the stabilization of the operating current and other indicators. Current sources in arc steel furnaces provide a reduction in metal consumption for smelting, eliminate the influence of the "short grid", increase the power consumption (cosφ, efficiency, harmonic ratio, etc.) [2]. In electrolysis plants is increased the productivity of the technological process, which is directly proportional to the current. Existing semiconductor converters with current source characteristics have advantages and also disadvantages. They are caused by nonlinear elements (diodes, thyristors) in the circuit, which worsens the quality of electricity and energy efficiency of electrical networks [3–5]. Therefore, the development and creation of efficient current converters is an important and urgent task [6].

2. Analysis of the work of current transformers for different types of loads

2.1. Active load (contact heating)
Contact heating is one of the methods of direct heating. Direct heating in comparison with indirect has the following advantages, it allows to increase labor productivity, significantly reduce metal losses to scale, extend the life of equipment, improve working conditions, etc.

Contact heating provides a high heating rate (tens of seconds). This is achieved through intensive electrical connection. Industrial contact heating installations are characterized by high currents (several tens of kilo amperes) and small applied voltages (5…25 V). One of the main disadvantages of industrial contact heating installations is their relatively low energy performance (efficiency is not more than 75%, power is about 0.8). Besides, without additional equipment, the output current can not be smoothly controlled [2, 7, 8].

2.2. Active - inductive load (arc furnace)
Arc furnaces are powerful consumers. They generally operate with a low power factor (0.7…0.8). The electric mode of arc furnaces is characterized by frequent technological short circuits (5…10 per minute). Some arc furnaces (vacuum arc furnaces) operate on direct current. In this case, the power supply must include an alternating current to direct current converter.

Vacuum arc furnaces are very sensitive to regime changes. Current fluctuations do not affect the quality of the ingot, if these fluctuations do not exceed 3 - 5%. Therefore, it is necessary to stabilize the current of the arc furnaces and its program change (regulation) for the time of welding and heating (the beginning of the melting), and for the time of the withdrawal of the shrinkage shell (melting end) [2, 9, 10].

2.3. Load in the form of counter- electromotive force (electrolysis of non-ferrous metals)
The work of electrolyzers is described by current-voltage characteristics (CVC) with small slopes in the working zone [10, 11]. A small slope of the current-voltage characteristic in the working zone makes it necessary to automatically stabilize the load current, because even slight variations in the grids voltage lead to a significant change in the current. So, when the grids voltage is reduced by 10% of the nominal value, the current of the zinc electrolyzers can be reduced by 10 to 50% [1].

3. Single-phase current parametric converters (CPC) for various types of loads
One of the ways to solve the problem of increasing the power indexes of gate converters is the development of CPC. They are compared with the traditional types of semiconductor converters have a power factor close to one and the natural current external characteristics [11–14].

3.1. Single-phase CPC for active load
Single-phase schemes of current parametric converters can be assembled by bridge or zero schemes. They are used usually at a relatively low power. The shape of the current in the load in single-phase current parametric converters does not depend on the scheme of the gate set, but is determined by the nature of the load. The scheme and time diagrams of the operation of a bridge single-phase current parametric converter are shown in Figure 1 and Figure 2, where I – is a parametric current source. Gates 1 to 4 operate in the order of the natural unlocking and provide in the load rectification mode. Latitudinal regulation of the load current is carried out by changing the duration of the short-circuited mode ($I_H = 0$).
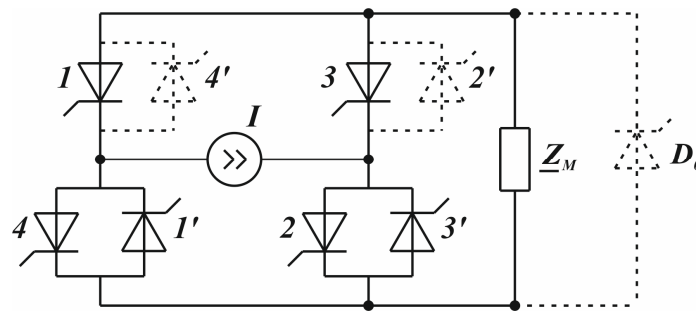
Figure 1. Single-phase scheme of CPC.

To ensure a short-circuited mode, two additional gates 1' and 3' are entered into the circuit. They are connected in parallel to gates 4 and 2. At the next clock cycle, instead of the gates 3 and 4 are included gates 3' or 4', the output of the parametric current source is short-circuited and the load current becomes zero. If it is necessary to adjust the duration of the pause, then at the next clock cycle includes gates 2, 1', and so on.

When the valves are turned on in the order of the natural unlocking, in the load restored a positive current value. Due to the characteristic features of the current parametric converters (the inadmissibility of idling, etc.), control impulses for the gates of CPC must be supplied only at the moment when the output current passes through zero.
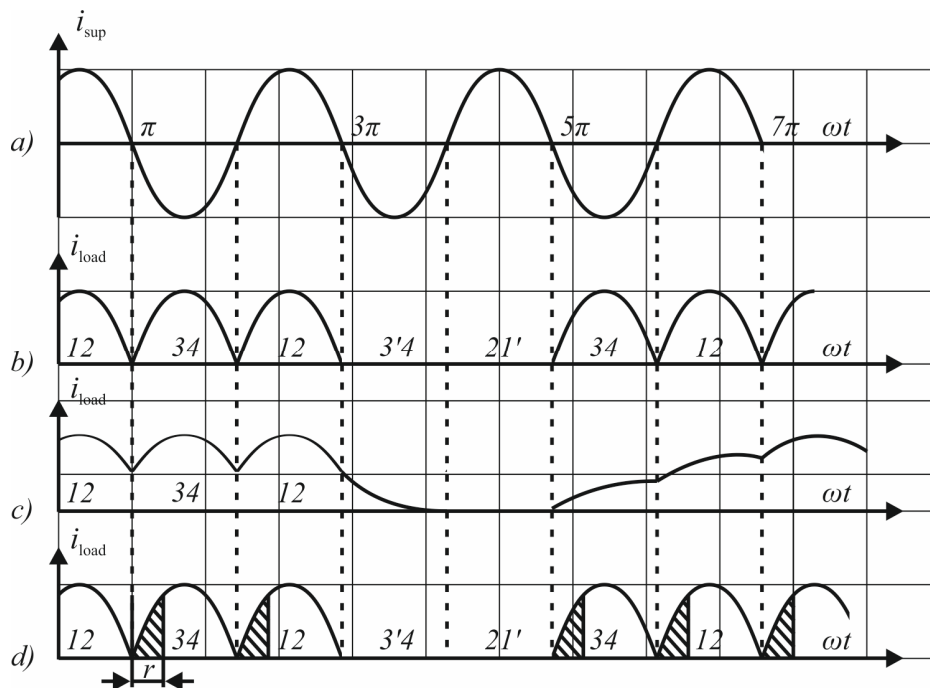

Figure 2. Time diagrams of single-phase current parametric converter operation (a) on the active load (*b*), on the active-inductive load (*c*), on the load in the form of counter-electromotive force (*d*).

Some consumers need a reverse load current [5]. To ensure the reversal of load current in the converter scheme are input two additional gates 2' and 4'. They are connected in parallel to the gates 3 and 1 (Figure 1). Then, at the next cycle, after a short-circuited mode (gates 2, 1' are turned on), the control pulses are applied to the converter gates 3', 4' and there is a smooth reverse of the load current.

3.2. Single-phase CPC for active-inductive load
The algorithms of operation of single-phase CPC on the active-inductive load are similar to those previously considered, when working on an active load. However, it is necessary to switch on an additional diode D_0 to provide a load-loop circuit in the short-circuited mode (Figure 1). The time diagrams of the load current of a single-phase CPC with an active-inductive load are shown in Figure 2*c*.

3.3. Single-phase CPC for loads in the form of counter-emf
A characteristic feature of the converter operation on the counter-emf is the presence of a commutation interval $\mathit{\Upsilon}$ (Figure 2*d*), the duration of which essentially depends on the load value and is determined by the recharge time of the capacitance of the parametric source within the limits from $-E_d$ up to $+E_d$. In this case, the current in the load does not flow in the switching interval.

It should be noted, the mode $I_H = 0$ allows only one-sided closing of the load during it operates on a counter-emf, since the two-sided closure is emergency. Reversing the load current when the CPC is running on the counter-emf (that is equal to E_d and the constant E_d polarity) is inadmissible, since a loop for two-sided closing of the load is formed through the operating rectifier bridge getes. Therefore, the reversal of the load current is only permissible if the polarity E_d is reversed. Time diagrams of operation of a single-phase converter in the operation of a counter-emf are shown in Figure 2*d*.

4. Conclusion
The most energy-consuming consumers of direct current are the electric technological plants (arc furnaces, etc.), which have a non-linear current-voltage characteristic with a low differential resistance. The quality of control of power that transmitted from source to consumer depends on the coordination of their characteristics. In the optimal case, these characteristics must be opposite, therefore, for consumers with a low differential resistance, current converters are necessary.

These requirements correspond to the current converters described in the article. These converters are based on a parametric current source and connected to the output of the gated sets (current-to-parameter converters) with the possibility of latitudinal control of the output current of the load, which is confirmed by the time diagrams of their operation.

In arc steel smelting furnaces, that are characterized by high operating currents, the use of current sources provides power stability in process short circuits, which significantly reduces the metal loss for melting, eliminates the influence of the "short grid", improves the power quality indicators.

In vacuum arc furnaces, when using of the proposed current parametric converters, the quality of remelted ingots significantly improves, the explosion safety of furnaces increases.

In electrolysis plants and electrochemical machining plants, the application of the CPC makes it possible to increase the productivity of the technological process, since it is directly proportional to the current.

In addition to electrothermal plants, the use of sources of stabilized direct current for an electric drive (electric drive with erection torque motor) is perspective [13, 15–18]. The converters considered in this article can be used in the practical design of secondary power supplies for powerful consumers.

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