Mode Characteristics of a Valve Converter Based on A Series Stand-Alone Current Inverter

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Abstract. The article analyzes the operating characteristics of a valve converter based on a series autonomous current inverter based on computer studies. It is shown that the valve converter circuit based on a series autonomous current inverter with a thyristor-choke compensating device not only provides the ability to regulate and stabilize the output parameters of the converter, but also helps to improve the dynamic properties of the converter due to the appearance of an additional recharging circuit for the switching capacitor. The obtained operating characteristics make it possible to determine the value of the control range that ensures stabilization of the output voltage while maintaining switching stability and, thereby, facilitates the determination of the optimal parameters of a valve converter based on a series autonomous current inverter.

Key words: valve converter, series autonomous current inverter, operating characteristics.

An important area of application of valve converters (VC) is their use as DC-DC converters with an adjustable output voltage, which are widely used to power DC motors, in various types of urban transport, on moving objects with a primary DC source (battery). In addition to those listed, it is worth highlighting special-purpose objects found in medicine, lighting engineering, optoelectronics, and automation, which require high direct voltage [1-3].

The article presents the results of computer studies on the basis of which the operating characteristics of two VC circuits based on a series autonomous current inverter were obtained.

Computer studies were carried out using a mathematical model and algorithm developed by the author earlier [4]. The mathematical model was developed using the Laplace transform and allows one to calculate the transient processes of the valve converter, taking into account the method of stabilizing the inverter output voltage. Recurrence relations were obtained to calculate the instantaneous values of the desired currents and voltages.

The original currents and voltages are expressed as::

$$i_1(t) = (E_d - E_л)/r_5 - (B_5/б_5 D_1)\exp(-б_5 t) + K_9 A_4 + K_{10} B_4;$$
$$i_k(t) = (E_л - E_d)/r_5 - (B_5/D_2)\exp(-б_5 t) - K_{11} A_4 + K_{12} B_4;$$
$$U_c(t) = r_k\,(E_d - E_л)/r_5 + (B_7/D_2)\exp(-б_5 t) + K_{11} A_6 + K_{12} B_6;$$
$$U_{mn}(t) = r_3\,(E_d - E_л)/r_5 - (B_9/б_5 D_1)\exp(-б_5 t) + K_9 A_8 + K_{10} B_8;$$
$$U_л(t) = E_л + r_л i_1(t).$$

It should be noted that when deriving recurrent relationships of the desired currents and voltages in this chapter, a functional separation of the coefficients included in the formulas was made. The coefficients, the value of which depends only on the parameters of the power circuit and does not depend on the type and lifetime of the NEO, are designated by the letters a_i, N_i, M_i. Coefficients, the value of which depends on the parameters of the power circuit and on the type of operator equivalent circuit (OEC), but does not depend on time, i.e. does not change during the existence interval of this OEC, are designated by the letters A_i, B_i. Coefficients, the value of which depends on both the parameters of the power circuit and the type of estimated time of this NEO, are designated by the letters K_i.

Thus, when calculating one version of the VC, the coefficients of the first type a_i, N_i, M_i are calculated once, since in the future their values remain unchanged; coefficients of the second type A_i, B_i. are calculated only when the structure of the power circuit changes, i.e. at the beginning of the calculation for a newly participating OEC, taking into account new independent initial conditions for this OEC; coefficients of the third type K_i, as well as the desired currents and voltages, are calculated as the calculated time changes. In this regard, we can say that the functional separation of coefficients eliminates duplication of calculation of the same coefficients, thereby reducing the redundancy of the general model and ensuring its speed.

The circuit of a stabilized power supply with pulse-frequency regulation is shown in Fig. 1. In this circuit, stabilization (regulation) of the load voltage is carried out by changing the frequency of the pulses supplied to the power thyristors of the inverter [5].

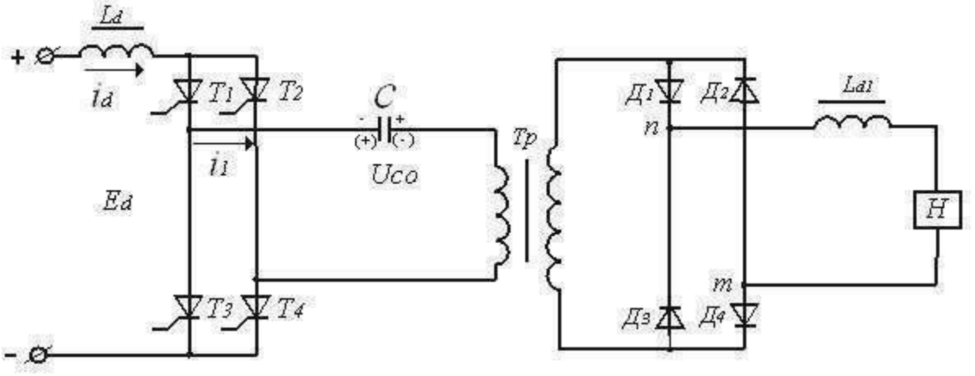


Fig.1. VC with adjustable output DC voltage based on a double energy converter.

Therefore, despite the simplicity and good control characteristics of the circuit (Fig. 1), at high operating frequencies, as well as in idle mode (low load current), the circuit may experience commutation failure. This drawback can be eliminated by introducing an additional circuit for recharging the switching capacitor into the inverter circuit. Such a circuit in the VC circuit in Fig. 2 is represented by an inductive thyristor compensating device (CD), connected in parallel with the switching capacitor C. The introduction of the CD allows not only faster recharging of the capacitor, i.e. provide stable switching, but also makes it possible to regulate and stabilize the output voltage.

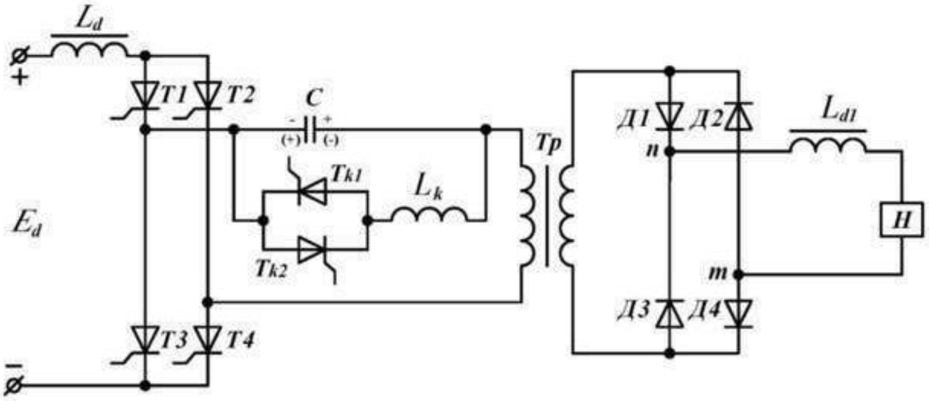
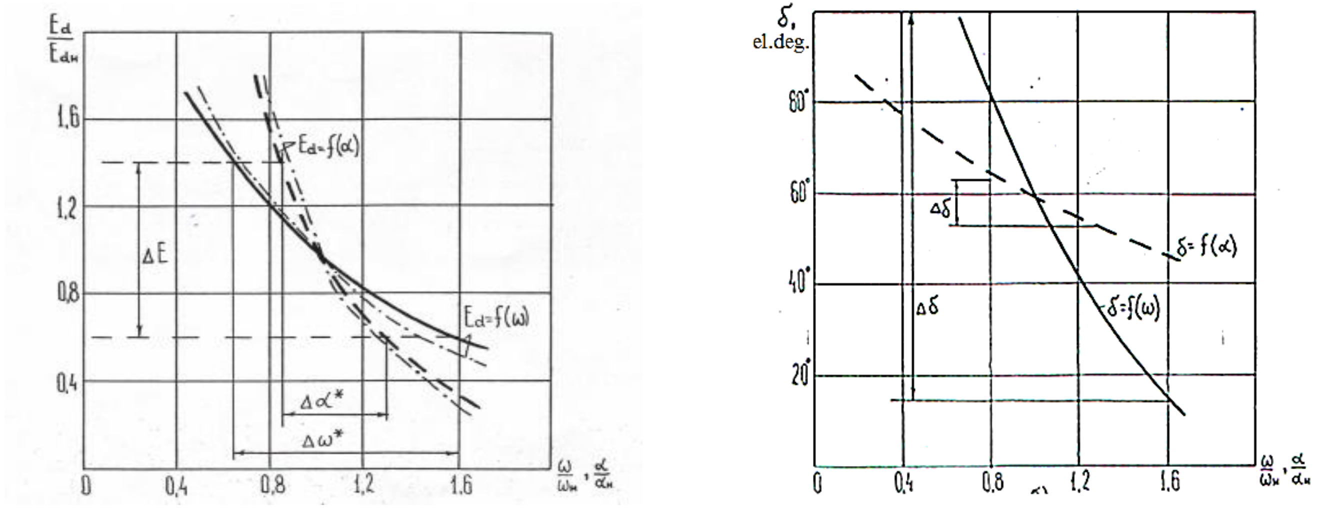


Fig. 2. VC with an adjustable output DC voltage based on a converter with double energy conversion with an inductive-thyristor compensating device.

To compare the technical capabilities of both circuits, a series of computer studies were carried out, on the basis of which the operating characteristics of these circuits were obtained for two methods of stabilizing the output voltage of the converter. To compare the capabilities of both control methods, their operating characteristics are combined (Fig. 3), while the solid lines show the characteristics obtained depending on ω^* (Fig. 3, a), while the dotted lines show the dependences on α^* (Fig. 3, b), where $\omega^*=\omega/\omega_{nom}$ and $\alpha^* = \alpha / \alpha_{nom}$. The operating characteristics $E_d^* = f(\omega^*)$ and $E_d^* = f(\alpha^*)$ were obtained by changing the input voltage E_d relative to E_{dnom} in the range from 0.2 to 1.8.



а)   б)

Fig. 3. Mode characteristics of VC based on sequential ACI:
P=const: a) $E_d^*=f(\alpha^*)$; $E_d^*=f(\omega^*)$; *б)* $\delta=f(\alpha^*)$; $\delta=f(\omega^*)$

The obtained characteristics make it possible to determine the value of ω or α, ensuring stabilization of the output parameters of the converter for a given change in E_d.

As can be seen from this figure, when E_d changes within + 40%, to maintain the stabilization mode, it is necessary to change α within 0.85 - 1.3 relative to α_{nom}, while ω must be changed within 0.65 - 1.6 relative to ω_{nom}. To maintain the stabilization mode during frequency regulation, compared to regulation by changing the angle α, it is necessary to change the control parameter (frequency) within a wide range.

To determine the values of the recovery angle δ for a given change in ω^*, α^*, ensuring stabilization while maintaining the switching stability of the converter in Fig. 3, *b* shows the dependence curves $\delta = f(\alpha)$ and $\delta = f(\omega)$. From these curves it is clear that with the same change in E_d (40% relative to E_{dnom}), the recovery angle during frequency regulation changes within the limits Δδ = 86 el. degrees and approaches the critical δ_{min} = 14 el. degrees, whereas when regulated by changing α, the limit of change is only 10 el. deg., a δ_{min} = 53 el. degrees. In this regard, it can be said that the VC with regulation through the CD has better control and switching properties than the VC with frequency regulation.

Summarizing the above, we can say that the introduction of a thyristor-inductor compensating device into the VC circuit based on a series ACI not only provides the ability to regulate and stabilize the output parameters, but also helps to improve the dynamic properties of the converter due to the appearance of an additional recharging circuit for the switching capacitor.

The obtained operating characteristics make it possible to determine the value of the control range that ensures stabilization of the output voltage while maintaining switching stability and, thereby, facilitates the determination of optimal VC parameters.

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