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ALGORITHMIC METHODS FOR DEVELOPING THE STRUCTURE OF A THYRISTOR ELECTRIC DRIVE FOR MINING MACHINES

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Annotation. *The article discusses the creation of algorithmic structures and the development of digital control systems for electric drives of mine-lifting machines, provides some concepts for creating digital control systems using thyristor converters. The analysis of the static volt-ampere characteristics of the thyristor is given, some calculations of the circuits and circuits of the thyristor converter (TP) corresponding to the different modes of operation of the TP are given, and also, based on the synthesis of the dynamic properties and characteristics of the thyristor, an algorithmic structure of the model of the thyristor converter is proposed.*
Keywords. *Thyristor converter,volt-ampere characteristic, dynamic characteristics, algorithmic structure, two-circuit regulation, digital control system,control object, nonlinear component element, models of thyristor converter.*

Аннотация: *Шахта юк кўтариш машиналари электр юритмалари рақамли бошқариш тизимларини ишлаб чиқиш ва алгоритмик структураларини тузиш усуллари кўриб чиқилган.Тиристорли ўзгарткичларни қўллаш асосида рақамли бошқариш тизимларинини тузишнинг бир қанча тамойиллари келтирилган. Тиристорнинг статик вольт-ампер тавсифи таҳлил қилинган, тиристорли ўзгарткичлар занжирларининг турли иш режимларига мос келувчи бир қанча ҳисоблари келтирилган, шунингдек, тиристорнинг динамик хоссаси ва тавсифларини синтезлаш асосида тиристорли ўзгарткичнинг моделини алгоритмик структураси таклиф этилган*
Таянч сўзлар: *тиристорли ўзгарткич, вольт-ампер тавсифи, дирамик тавсифлар, алгоритмик структура, икки контурли ростлаш, рақамли бошқариш тизими,бошқариш объекти, тиристорли ўзгарткич модели.*

Аннотация. *Рассматрываются вопросы создания алгоритмических структур и разработки цифровых систем управления электроприводами шахто-подъемных машин, приводятся некоторые концепции создания цифровых систем управления с применением тиристорных преобразователей. Выполнен анализ статической вольт-амперной характеристики тиристора, приведени некоторые расчеты схем и цепи тиристорного пребразователя (ТП) соответветствующих разичным режимам работы ТП. На основе синтеза динамических свойств и характеристик тиристора предлагается алгоритмическая структура модели тиристорного преобразователя.*
Ключевые слова. *Тиристорный преобразователь, вольт-амперная характеристика, динамические характеристики, алгоритмическая структура, двухконтурное регулирование, цифровая система управления,объект управления, модели тиристорного преобразователя.*

Solutions to the problem of increasing the operational reliability of the electric drive system of mining machines are developing in two main directions, the first is to improve the mechanical transmission systems of converters, and the second is to use an automated electric drive based on digital elastic stress control technologies without reducing the torque on the working body of the mining machine.

In mining and technological processes for the transportation of ore in the relevant mine directions, the main technical means are mine lifting installations.

In turn, thyristor converters are used as the main link in the electric drive systems of mine-lifting installations. They are the main converters of electrical energy and the required quality of control and reliability of electric drive control depend on their dynamic parameters.

With the development of microprocessor control systems, on the basis of which pulse-phase control systems (SIFU) of thyristor converters are implemented, it becomes possible to create new algorithms that ensure more reliable functioning of control subsystems and at the same time allow for operational adjustments in the diagnostics of the control system, taking into account the nonlinearities of characteristics and their compensation in the thyristor converter itself.

Currently, in most industries, systems based on analog circuit solutions are mainly used to control the operation of mine mechanisms in operation, which do not have sufficient noise immunity, compared with small integrated capabilities for creating standard networks and automated production management systems.

In the newly created systems based on digital circuitry, there are opportunities for a more accurate implementation of structural algorithms that allows you to design the most flexible, high-speed control systems that meet modern requirements.

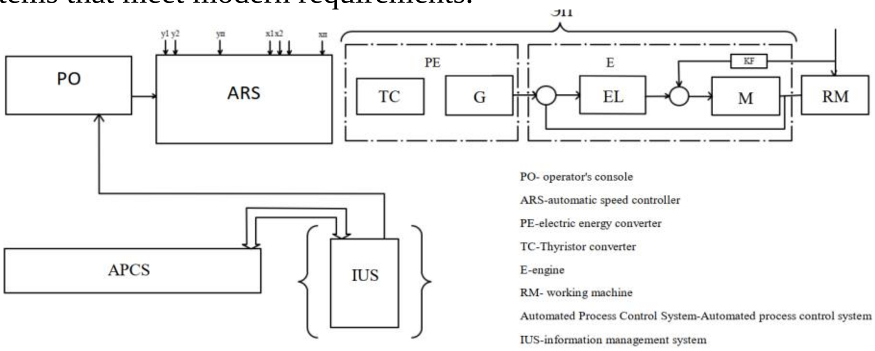

Figure. 1. ***Block diagram of a control system with a thyristor electric drive.***

The recommended systems with dual-circuit speed control, (Fig. 2) which uses an internal circuit for voltage, as well as an external circuit for EMF, is the most promising with the possibility of implementing the system itself and ensuring accuracy despite the need to create an additional external circuit to limit current emissions. To ensure the stability of the control system in such systems to various changes in the parameters of the electric drive, it is necessary to properly organize the implementation of the EMF sensor.

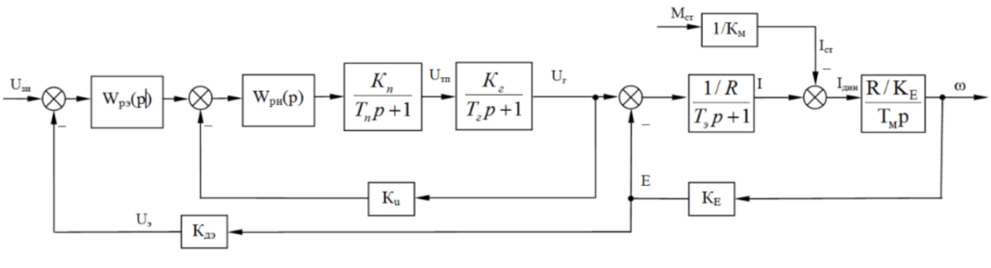

Figure. 2. ***Structural and algorithmic scheme of two-circuit regulation with a thyristor converter.***

In modern electric drives with digital control systems, it becomes possible to implement software-algorithmic pulse-phase control systems, in which all functions of regulators are performed on the basis of microprocessors.

In these digital systems, the z-transformation is used to describe the real properties of objects [2,9].

Then, using the lattice function y[k] to describe the properties of this system using the Z-transformation, you can write in the following expressions:

$$Z\big[y[k]\big] = Y(z) = \sum_{k=0}^{\infty} z^{-k} y[k]; \quad (1)$$

$$Z^{-1}[Y(z)] = y[k] = \frac{1}{2\pi j}\oint z^{k-1}Y(z)dz. \quad (2)$$

Note also that the Laplace transform for the described system is appropriate using the expression:

$$L[y(t)] = \int_0^\infty e^{-st}\ y\,(t)dt. \quad (3)$$

In order to proceed to delta transformations in the descriptions, it is necessary to keep a discrete time value tk = kΔ and, accordingly, we have,

$$e^{s\Delta} = 1 + \gamma\Delta = k\Delta;$$

$$D[y(k\Delta)] = Y_\delta(\gamma) = \sum_{k=0}^{\infty}(1+\gamma\Delta)^{-k}y(k\Delta)\Delta, \quad (4)$$

$$D^{-1}[Y_\delta(\gamma)] = y(k\Delta) = \frac{1}{2\pi j}\oint(1+\gamma\Delta)^{k-1}\,Y_\delta(\gamma)d\gamma \quad (5)$$

Bearing in mind that the delta transformation and the z-transformation used in our system are related by the following relation,

$$Y_\delta(\gamma) = \Delta Y_q(z)\big|_{z=\Delta\gamma+1}; \quad (6)$$

$$Y_q(z) = \frac{1}{\Delta}Y_\delta(\gamma)\big|_{\gamma=\frac{z-1}{\Delta}} \quad (7)$$

Note that the main properties of delta transformations are that they are similar to Laplace transformations only for values $\Delta \to 0$:

$$lim_{\Delta\to 0}Y_\delta(\gamma) = Y(s)|_{s=\gamma}. \quad (8)$$

For an analytical description of the thyristor converter as an object of control and synthesis of the proposed structure of the system, it is necessary first of all to analyze the properties of the thyristor converter.

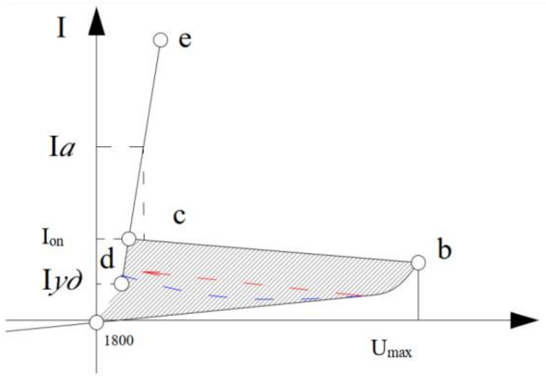

Figure. 3. ***Graph of the volt-ampere characteristic of the thyristor.***

The volt-ampere characteristic of the thyristor in question, shown in Fig. 3, can be represented as a non-linearly varying active resistance,

$$R_{VS} = f\big(U_{VS}(t)\big), i_{VS}(t), i_{VS}(t), i_y(t), t, S). \quad (9)$$

Applying approximation methods, it is possible to characterize the operation of the thyristor corresponding to different modes. Neglecting the switching time of the thyristor, small changes in the capacitance and inductance parameters that occur in the crystal structure of the semiconductor, as well as some of the plot shown in the VAC graph, for example: $a-b$, $a-f$ and $d-e$ can be taken as linear. At the same time, given that the control current changes discretely and the numerical value of which is compared to the rectification current $Iy,c.$:

The various modes of operation of the thyristor are controlled by the corresponding pulses, for example, to switch to the on state with the input of the on current I_{on}, the reverse switching to the off state occurs by the absence of a holding current $I_{yд}$ [3]. The corresponding formulas for these processes can be described in the following expressions:

$$R(t_{off\,imp}) = R_1 t\ t_{off\,imp}, if\ i_{VS} > 0\ u\ (U_{VS}\,R_{close} < i_{VS} < I_{on})\ and\ S = 0, \quad (10)$$

$$R_{a-d} = R_{on}\,,\ if\ U_{VS} \geq 0\ u\ S = 0\ u\ (i_Y = I_{\,y.c}), \quad (11)$$

here R1 is the tuning coefficient, which depends on the design of the thyristor and determines the change in active resistance; Ron – the specific value of the active resistance of the thyristor in the on mode; t – cycle time; $t_{off\ imp}$– the value of the shutdown time interval.

Thus, the algorithmic model of the thyristor circuit can be formulated by the following relations:

$$R_{VS} = \begin{cases} R_{a-f} = R_{close}, & if\ i_{VS} \leq 0\ or\ U_{VS} < 0, \\ R_{a-b} = R_{close}, & if\ U_{VS} \geq 0 \text{ и } S = 0\ and\ i_Y = 0 \text{ и } i_{VS} \leq U_{VS}/R_{close}, \\ R_{d-e} = R_{open}, & if\ U_{VS} \geq 0\ \ i_{VS} > I_{y\partial}\ and\ S = 1, \\ R_{a-d} = R_{on}, & if\ U_{VS} \geq 0 \text{ и } S = 0 \text{ и } i_Y = I_{y.c}, \\ R(t_{off\ imp}) = R_1 t_{off\ imp} & if\ \ i_{VS} > 0\ and\ (U_{VS}/R_{close} < i_{VS} < I_{on}) and\ S = 0. \end{cases} \tag{12}$$

Then, the expression defining the thyristor states can be represented by

$$S = \begin{cases} 0, & if\ U_{VS} < 0\ or\ i_{VS} < I_{y\partial}, \\ 1, & if\ U_{VS} \geq 0\ and\ i_{VS} < I_{on}, \\ S, & in\ all\ other\ cases, \end{cases} \tag{13}$$

Noting that the proportionality coefficient R1 depends on the structural elements of the thyristor.

According to the one-half-period rectification scheme, the model for a single thyristor can be represented as in Figure 8.

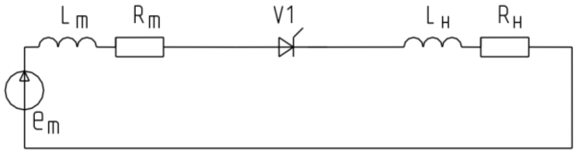

Figure. 4. ***Equivalent circuit diagram of a single-phase single-half-period thyristor rectifier.***

The following expression corresponds to the calculation scheme

$$(L_T + L_{\text{H}})\frac{di}{dt} + [R_T + R_{VS} + R_{\text{H}}]i = e_T(t), \tag{14}$$

Assuming that the thyristor model consists of a set of three structural composite models: a model corresponding to the load described by equation (14), a model corresponding to the dynamic state of the thyristor described by a system of equations (12) and a model of nonlinear components of the element described by a system of equations (13) and it is possible to represent the structure of a thyristor converter.

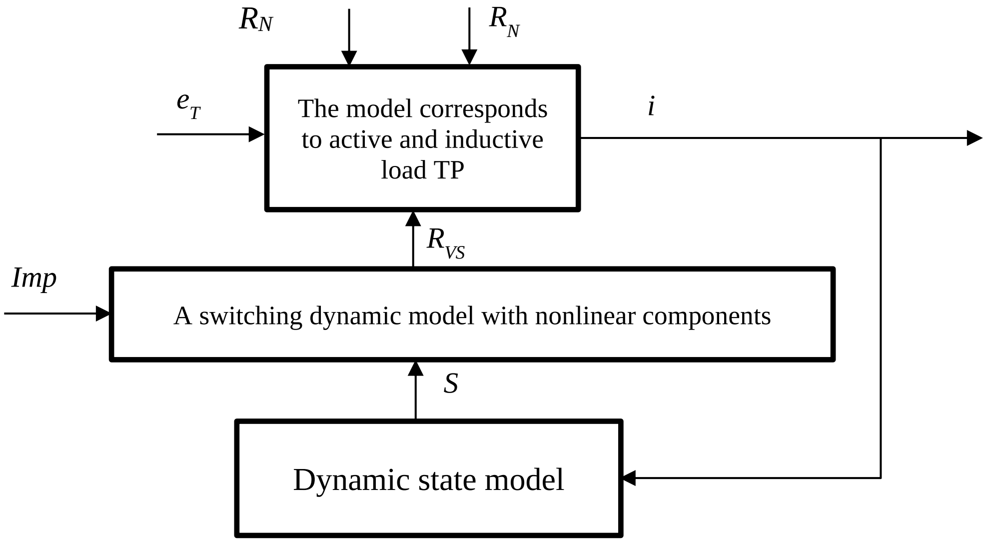

Figure 5. ***Structural components of the thyristor model.***

In Fig. 5: eT is the EMF value in the transformer circuit, Imp is the supplied control pulse, which is generated by the control system.

The generated control pulse signal is expressed with the following ratio.

$$\sum Imp = f \sum \overline{(Imp)} = \cup (Imp_i = 1 \cap Imp_{i+1} = 0). \tag{15}$$

The signal coming from the voltage switch can be represented as an equation

$$U_d *= f_U(U_{AB,}U_{CA}, U_{BC}, \overline{Imp}) = \begin{cases} U_{AB}, \; if \; Imp *_1 = 1, \\ -U_{CA}, if \; Imp *_2 = 1, \\ -U_{BC}, \; if \; Imp *_3 = 1, \\ -U_{AB}, if \; Imp *_4 = 1, \\ U_{CA}, if \; Imp *_5 = 1, \\ -U_{BC}, if \; Imp *_6 = 1, \end{cases} \tag{16}$$

here U_{AB}, U_{CA}, U_{BC} – sinusoidal supply voltages of the three component circuits of the thyristor converter.

The functions and direction of the reverse are carried out by the bridge selection unit in accordance with the signal from the logic device

$$U_d = f_M(U_d *, TM_1, TM_2) = \begin{cases} U_d *, if \; TM_1 = 1, TM_2 = 0; \\ -U_d *, if \; TM_1 = 0, TM_2 = 1; \\ 0, if \; TM_1 = 0, TM_2 = 0; \end{cases} \qquad 17)$$

TM1, *TM2* – control logic signals for direction selection.

From the system of equations (17), it is possible to calculate the differential ratio describing the active and inductive load TP:

$$\frac{di}{dt} = \frac{1}{L}(-(R + R_V)i + U_d - E), \tag{22}$$

here E is a parameter defined as the counter-EMF of the load.

By solving the differential equation (22) at zero initial values corresponding to the interval under consideration, it is possible to determine the real value of the load current of the thyristor converter:

$$i = f_I(U_d, R_V, R, L, E). \tag{23}$$

Using system expressions (14), (15) and expressions (19)-(23), it is possible to construct the structure of the thyristor converter model in the form shown in Figure 6.

The following signals are marked in the given structure: *Imp* – generated control pulses coming from the pulse-phase control system (PPCS); *Imp** – control pairs of pulses from the memory block that are used for switching dedicated line voltage pairs; *ΣImp* – the required total control pulse, for the bridge selection unit performing reverse control; *ΣImp** – a set of pulses that determine the operating modes of the thyristor bridge.

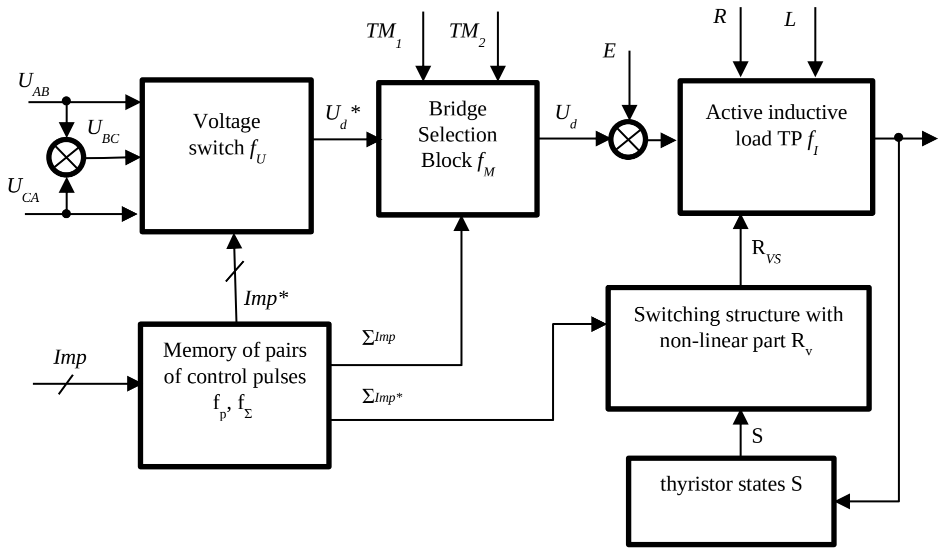

Figure. 6. ***Algorithmic structure of the thyristor converter model.***

The switch generates a signal in the form of voltage Ud*, determined in accordance with expression (20), with the arrival of a signal Imp*. The bridge selection unit performs the reset function, or performs signal reversal Ud* according to the mode of operation of the converter. Received voltage signal *Ud*, it is fed into the next thyristor unit – the active-inductive load unit, which accordingly generates a signal that subsequently determines the state of the thyristor.

Thus, the obtained algorithmic structural model of the thyristor converter determines all the necessary calculated nonlinear dynamic characteristics of the thyristor and makes it possible to describe the basic properties of thyristor converters corresponding to the three operating modes:

-continuous current mode in the converter circuit;

- the mode corresponding to the intermittent current in the circuit;

-mode, the absence of current when the converter circuit is dominated by a large inductance and locking of the thyristor.

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