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MATHEMATICAL MODEL FOR THE DETERMINATION OF DISCHARGERS' RESIDUAL WORKING RESOURCE AND THE DEVICE FOR ITS REALIZATION

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Abstract – The paper considers the mathematical model for dischargers diagnosing, considering the value and the duration of the current's impulse at the moment of commutation and synthesized the device for its realization using the sequence's mathematical tool.

Keywords: discharger, resource, device.

1. INTRODUCTION

It's known, that the dischargers are used in electric network systems to protect the power electric equipment from lightning surge and commutation overvoltage [1]. The main power electric equipment operating reliability is determined by the corresponding reliability of the work of dischargers. As is known, operating resource of the latter essentially depends on the value and duration of the currents, flowing through the discharger at the moment of overvoltage limiting.

It is shown [2], that the main element of the discharger, except the spark gap, is nonlinear resistance, which consists of nonlinear elements (NE), the quantity of which is determined by the class of voltage, character of the work and performance. There's also the data, which shows the dependence of the currents' value on the quantity of their transmissions through NE considering the duration of the impulses. So, for instance, for the NE, made of tervit (diameter of the disk is 70 mm, height is 30 mm) there is the dependence that's shown in the table 1.

Table 1. Discharger's dependence on the commutation parameters.

Duration of impulse τ, μs	Quantity of impulses, n	The value of the current I, kA
18/40	Not less than 20	16
3000/8000	Not less than 20	0,5

Apart from that, there are formulas in [2]:

$$n \cdot I^k = \text{const}, \qquad (1)$$

$$I \cdot \tau^m = \text{const}, \qquad (2)$$

where the factor k = 3 for τ=18/40 μs, and factor m=0,65 for the range of the current waves length τ 40 μs – 8 ms.

The task of the discharger's residual resource determination appears in case when the actual current values differ from the data shown in the table.

2. REALIZATION OF THE MATHEMATICAL MODEL FOR DISCHARGER'S DIAGNOSING

It's obvious, that according to the formula (1) it is easy to find the correlation of different current values I, that flow through NE with the corresponding values of the impulses quantity n.

Let's show, for instance, such a dependence in the kind of a table 2 for τ=18/40 μs.

Table 2. Dependence n=f(I).

I (kA)	16	12	8	4
n	20	47.4	160	1280

It is obvious, that the same way makes it possible to find another correlation between I and n for any current's wavelength.

The analysis of the formula (1) and the data in the table (2) helps assert that the resource characteristic of NE is similar to the resource characteristic of high-voltage switcher, the example of receiving the latter is given in the work [3].

If every correlation of I and n of NE is known, it's possible to get the mathematical model for the determination of its residual working resource under a certain length of the current's wave. The following approach should be applied for this.

Let's assume that the minimal current value (according to the table 2), that flows through NE, is I_{min}=4 kA. Then, within one commutation the residual resource of NE is reduced by the value

$$r_{min} = \frac{1}{n_{min}} = \frac{1}{1280} = 7{,}81 \cdot 10^{-4}, \qquad (3)$$

where n_{min} – the number of current commutations I_{min}.

Similarly, the flowing of any other current value I_i will cause the corresponding depletion of working resource

$$r_i = \frac{1}{n_i}. \qquad (4)$$

By formulas (3) and (4) a factor is found

$$q_i = \frac{r_i}{r_{min}}, \qquad (5)$$

which characterizes the degree of NE working resource consumption when commutating the i-th current value.

If the number of the commutation of the i-th current value is marked as m_i, then the correlation $m_i q_i$ will characterize an NE working resource consumption under the execution of these commutations, and the expression $\sum_{i=1}^{N} q_i m_i$ shows how NE working resource is consumed at N different current values commutation, the flowing number of each of them equals m_i.

So, finally the NE residual working resource when determining the length of current's wave, may be determined by the formula:

$$R = n_{min} - \sum_{i=1}^{N} q_i \cdot m_i \,. \qquad (6)$$

We should note, that value N is unknown previously, and while realizing technical systems it is necessary to foresee the continuous tracing of the degree of NE working resource depletion and to forecast the possibility of the each following commutation with a certain degree of uncertainty.

Let's use the specific example to illustrate how to determine the residual working resource of NE, by which is made, for instance, one commutation of the 16 kA current, seven commutations of the 8 kA current and ten commutations of the 4 kA current, when the 4 kA value of the current is considered as the minimal.

By formula (4) the depletion of working resource under the 16 kA and 8 kA current commutations is found:

$$r_1 = \frac{1}{n_1} = \frac{1}{20} = 0{,}05 \,,$$

$$r_2 = \frac{1}{n_2} = \frac{1}{160} = 6{,}25 \cdot 10^{-3} \,.$$

By formula (5) the corresponding factor is found:

$$q_1 = \frac{r_1}{r_{min}} = \frac{0{,}05}{7{,}81 \cdot 10^{-4}} \approx 64 \,,$$

$$q_2 = \frac{r_2}{r_{min}} = \frac{6{,}25 \cdot 10^{-3}}{7{,}81 \cdot 10^{-4}} \approx 8 \,.$$

It is obvious, that $q_3 = 1$, because the minimal accepted value of the current, which flows through the NE equals 4 kA.

By formula (6) the residual resource of NE is found:

$$R = n_{min} - (q_1 m_1 + q_2 m_2 + q_3 m_3) =$$
$$= 1280 - (64 \cdot 1 + 8 \cdot 7 + 1 \cdot 10) = 1150.$$

So, the residual working resource of NE equals 1150 commutations of the accepted value of the minimal current.

It's necessary to point out, that the recalculation of working resource is possible to be made at any accepted minimal NE commutation current.

Using the formula (2) it is possible at the same way to get resource characteristics of dischargers for any length of current impulse.

It's known that the discharger is realized by the consecutive and parallel switching of certain quantity of NE [2]. So, having determined according to the particular scheme of switching NE the resource characteristic of the whole discharger, it's easy to realize the device for the determination of the whole discharger residual working resource.

3. THE SYNTHESIS OF THE STRUCTURE OF THE DEVICE FOR CONTROLLING OVER THE DISCHARGERS' RESOURCES

The structure of the device for dischargers' working resource control is synthesized on the base of the suggested mathematical model.

The synthesis of the calculator of device's resource is realized using the sequence's mathematical tool, the advantages of using of which are shown in [4].

It is obvious, that the controlling device has to contain the current sensor and the normalizing converter. The definite factor, which helps calculate an exhaustion process of the discharger's commutation resource under the certain length of current impulse corresponds to any value of the current, which flows through the discharger.

As an example, let's show the process of the synthesis of the device for working resource controlling only for three values of the commutated current with the weighting coefficients equal 1, 2 and 3 under the certain length of current impulse and for three values of the commutated current with the weighting coefficients equal 2, 3 and 4 when the length of current impulse is bigger than the previous one, though the number of weighting coefficients is much more bigger under the real conditions.

According to the synthesis practice, let's describe every component, which is the part of the synthesized device.

When developing across each range of the current, the comparator [5] is used. Let's mark the determination of the value of the impulse current in the first, second and third ranges by symbols I_1, I_2, I_3 correspondingly. Let's mark the value of the currents, which are out of the corresponding ranges by symbols $\bar{I}_1$, $\bar{I}_2$, $\bar{I}_3$.

The three triggers will be used for the fixing of three different ranges of the current. Let's introduce T_2, T_3, T_4 – the triggers, fixing the first, second and third ranges of the current accordingly.

To determine the length of the current impulse, it is necessary to use the impulses' counter, saving the impulses, which correspond to the certain length of these impulses. Let's introduce three triggers T_5, T_6, T_7, to simulate the impulses' counter, and a trigger T_1 for the realization of the generator aimed at forming these impulses with time delay for switching τ_1 and τ_2, considering $\tau_1 < \tau_2$.

When the discharger comes into action and the current, fixed by the comparator, flows through it, the definite number of the impulses, depending on the length of the current impulse and the value of the commutated current should enter the counter of discharger's residual resource. This number of impulses is set by weighting factors, the dependence of forming of which on the value of the commutated current is simulated by the impulses' counter.

Let's introduce the triggers T_{10}, T_{11}, T_{12} and T_{13} to simulate such impulses' counter, and for the forming of the impulses which are applied to this counter we introduce the impulses' generator, realized on the trigger T_8 with the time delays τ_3 and τ_4, considering $\tau_3 < \tau_4$. It should be noted, that the execution of $(\tau_1 + \tau_2) << (\tau_3 + \tau_4)$ is necessary for accurate work of the device.

Furthermore, it is necessary to introduce into the structure of the device one more trigger T_9 with corresponding time delay τ_3 to bring all the triggers into the original state upon the termination of the cycle of «measuring of length of the current impulses and the value of the current – the registration of the corresponding number of impulses in the counter».

In the moment of the application of the supply voltage to clear all the triggers and their preparation for the work cycle, it is necessary to introduce the signal R into the device.

Taking into consideration the above remarks, the graph of the functioning of the device for controlling the discharger's working resource looks as shown on Fig. 1:

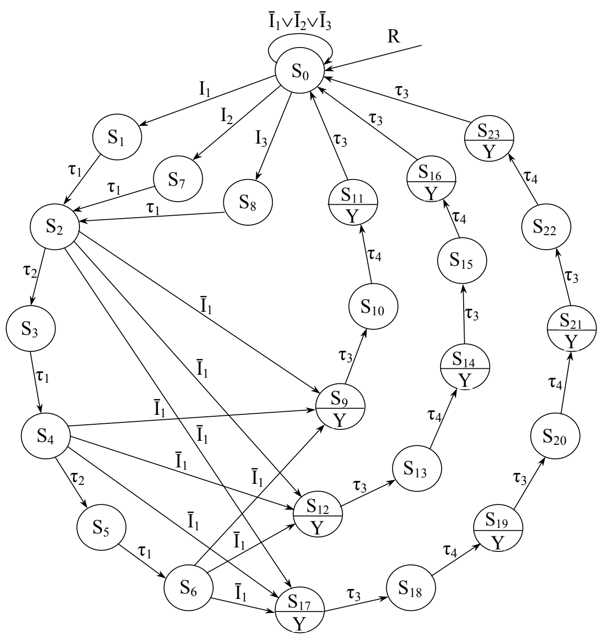

Fig. 1. The graph of the functioning of the device for controlling the discharger's working resource

Analytically the functioning of the device for controlling the discharger's working resource is described in accordance with the graph by the sequence's system

$$
\left\{
\begin{array}{rlrl}
R \vdash & S_0; & I_3S_0 \vdash & S_8; \\
\bar{I}_1 \vee \bar{I}_2 \vee \bar{I}_3 \vdash & S_0; & \tau_1 S_7 \vdash & S_2; \\
I_1S_0 \vdash & S_1; & \tau_1 S_8 \vdash & S_2; \\
\tau_1 S_1 \vdash & S_2; & \tau_3 S_9 \vdash & S_{10}; \\
\tau_2 S_2 \vdash & S_3; & \tau_4 S_{10} \vdash & S_{11}; \\
\tau_1 S_3 \vdash & S_4; & \tau_3 S_{11} \vdash & S_0; \\
\tau_2 S_4 \vdash & S_5; & \tau_3 S_{12} \vdash & S_{13}; \\
\tau_1 S_5 \vdash & S_6; & \tau_4 S_{13} \vdash & S_{14}; \\
\bar{I}_1 S_2 \vdash & S_9; & \tau_3 S_{14} \vdash & S_{15}; \\
\bar{I}_1 S_2 \vdash & S_{12}; & \tau_4 S_{15} \vdash & S_{16}; \\
\bar{I}_1 S_2 \vdash & S_{17}; & \tau_3 S_{16} \vdash & S_0; \\
\bar{I}_1 S_4 \vdash & S_9; & \tau_3 S_{17} \vdash & S_{18}; \\
\bar{I}_1 S_4 \vdash & S_{12}; & \tau_4 S_{18} \vdash & S_{19}; \\
\bar{I}_1 S_4 \vdash & S_{17}; & \tau_3 S_{19} \vdash & S_{20}; \\
\bar{I}_1 S_6 \vdash & S_9; & \tau_4 S_{20} \vdash & S_{21}; \\
\bar{I}_1 S_6 \vdash & S_{12}; & \tau_3 S_{21} \vdash & S_{22}; \\
\bar{I}_1 S_6 \vdash & S_{17}; & \tau_4 S_{22} \vdash & S_{23}; \\
I_2 S_0 \vdash & S_7; & \tau_3 S_{23} \vdash & S_0; \\
\multicolumn{4}{c}{S_9 \vee S_{11} \vee S_{12} \vee S_{14} \vee} \\
\multicolumn{4}{c}{\vee S_{16} \vee S_{17} \vee S_{19} \vee S_{21} \vee S_{23} \vdash Y;} \\
\multicolumn{4}{c}{S_0 \vee S_1 \vee S_2 \vee S_3 \vee S_4 \vee S_5 \vee S_6 \vee S_7 \vee} \\
\multicolumn{4}{c}{\vee S_8 \vee S_{10} \vee S_{13} \vee S_{15} \vee S_{18} \vee S_{20} \vee S_{22} \vdash \overline{Y}}
\end{array}
\right. \qquad (7)
$$

under the condition, that

$$
\left\{
\begin{array}{l}
\bar{T}_1\bar{T}_2\bar{T}_3\bar{T}_4\bar{T}_5\bar{T}_6\bar{T}_7\bar{T}_8\bar{T}_9\bar{T}_{10}\bar{T}_{11}\bar{T}_{12}\bar{T}_{13} \in S_0; \\
T_1T_2\bar{T}_3\bar{T}_4T_5\bar{T}_6\bar{T}_7\bar{T}_8\bar{T}_9\bar{T}_{10}\bar{T}_{11}\bar{T}_{12}\bar{T}_{13} \in S_1; \\
\bar{T}_1T_2\bar{T}_3\bar{T}_4T_5\bar{T}_6\bar{T}_7\bar{T}_8\bar{T}_9\bar{T}_{10}\bar{T}_{11}\bar{T}_{12}\bar{T}_{13} \in S_2; \\
T_1T_2\bar{T}_3\bar{T}_4T_5T_6\bar{T}_7\bar{T}_8\bar{T}_9\bar{T}_{10}\bar{T}_{11}\bar{T}_{12}\bar{T}_{13} \in S_3; \\
\bar{T}_1T_2\bar{T}_3\bar{T}_4T_5T_6\bar{T}_7\bar{T}_8\bar{T}_9\bar{T}_{10}\bar{T}_{11}\bar{T}_{12}\bar{T}_{13} \in S_4; \\
T_1T_2\bar{T}_3\bar{T}_4T_5T_6T_7\bar{T}_8\bar{T}_9\bar{T}_{10}\bar{T}_{11}\bar{T}_{12}\bar{T}_{13} \in S_5; \\
\bar{T}_1T_2\bar{T}_3\bar{T}_4\bar{T}_5T_6T_7\bar{T}_8\bar{T}_9\bar{T}_{10}\bar{T}_{11}\bar{T}_{12}\bar{T}_{13} \in S_6; \\
T_1T_2T_3\bar{T}_4T_5\bar{T}_6\bar{T}_7\bar{T}_8\bar{T}_9\bar{T}_{10}\bar{T}_{11}\bar{T}_{12}\bar{T}_{13} \in S_7; \\
T_1T_2T_3T_4T_5\bar{T}_6\bar{T}_7\bar{T}_8\bar{T}_9\bar{T}_{10}\bar{T}_{11}\bar{T}_{12}\bar{T}_{13} \in S_8; \\
\bar{T}_1T_2\bar{T}_3\bar{T}_4T_5\tilde{T}_6\tilde{T}_7T_8T_9T_{10}\bar{T}_{11}\bar{T}_{12}\bar{T}_{13} \in S_9; \\
\bar{T}_1T_2\bar{T}_3\bar{T}_4T_5\tilde{T}_6\tilde{T}_7\bar{T}_8T_9T_{10}\bar{T}_{11}\bar{T}_{12}\bar{T}_{13} \in S_{10}; \\
\bar{T}_1T_2\bar{T}_3\bar{T}_4T_5\tilde{T}_6\tilde{T}_7T_8T_9T_{10}T_{11}\bar{T}_{12}\bar{T}_{13} \in S_{11}; \\
\bar{T}_1T_2T_3\bar{T}_4T_5\tilde{T}_6\tilde{T}_7T_8T_9T_{10}\bar{T}_{11}\bar{T}_{12}\bar{T}_{13} \in S_{12}; \\
\bar{T}_1T_2T_3\bar{T}_4T_5\tilde{T}_6\tilde{T}_7\bar{T}_8T_9T_{10}\bar{T}_{11}\bar{T}_{12}\bar{T}_{13} \in S_{13}; \\
\bar{T}_1T_2T_3\bar{T}_4T_5\tilde{T}_6\tilde{T}_7T_8T_9T_{10}T_{11}\bar{T}_{12}\bar{T}_{13} \in S_{14}; \\
\bar{T}_1T_2T_3\bar{T}_4T_5\tilde{T}_6\tilde{T}_7\bar{T}_8T_9T_{10}T_{11}\bar{T}_{12}\bar{T}_{13} \in S_{15}; \\
\bar{T}_1T_2T_3\bar{T}_4T_5\tilde{T}_6\tilde{T}_7T_8T_9T_{10}T_{11}T_{12}\bar{T}_{13} \in S_{16}; \\
\bar{T}_1T_2T_3T_4T_5\tilde{T}_6\tilde{T}_7T_8T_9T_{10}\bar{T}_{11}\bar{T}_{12}\bar{T}_{13} \in S_{17}; \\
\bar{T}_1T_2T_3T_4T_5\tilde{T}_6\tilde{T}_7\bar{T}_8T_9T_{10}\bar{T}_{11}\bar{T}_{12}\bar{T}_{13} \in S_{18}; \\
\bar{T}_1T_2T_3T_4T_5\tilde{T}_6\tilde{T}_7T_8T_9T_{10}T_{11}\bar{T}_{12}\bar{T}_{13} \in S_{19}; \\
\bar{T}_1T_2T_3T_4T_5\tilde{T}_6\tilde{T}_7\bar{T}_8T_9T_{10}T_{11}\bar{T}_{12}\bar{T}_{13} \in S_{20}; \\
\bar{T}_1T_2T_3T_4T_5\tilde{T}_6\tilde{T}_7T_8T_9T_{10}T_{11}T_{12}\bar{T}_{13} \in S_{21}; \\
\bar{T}_1T_2T_3T_4T_5\tilde{T}_6\tilde{T}_7\bar{T}_8T_9T_{10}T_{11}T_{12}\bar{T}_{13} \in S_{22}; \\
\bar{T}_1T_2T_3T_4T_5\tilde{T}_6\tilde{T}_7T_8T_9T_{10}T_{11}T_{12}T_{13} \in S_{23}.
\end{array}
\right. \qquad (8)
$$

Let's apply the rules of minimization of the sequences to (7) and (8) according to [4], and get

$$
\left\{
\begin{array}{l}
\begin{array}{rlrl}
\tau_2 I_1 \bar{T}_1 \vdash & T_1; & \tau_4 \bar{I}_1 \bar{T}_8 T_2 \vdash & T_8; \\
I_1 \vdash & T_2; & \tau_3 T_8 \vdash & \bar{T}_8; \\
\tau_1 T_1 \vdash & \bar{T}_1; & T_8 \vdash & T_{10}; \\
T_1 \vdash & T_5; & \tau_4 T_{10} T_8 \vdash & T_{11}; \\
\tau_2 T_5 T_1 \vdash & T_6; & \tau_4 T_{11} T_8 \vdash & T_{12}; \\
\tau_2 T_6 T_1 \vdash & T_7; & \tau_4 T_{12} T_8 \vdash & T_{13}; \\
I_2 \vdash & T_3; & T_8 \vdash & Y; \\
I_3 \vdash & T_4; & &
\end{array} \\
T_2T_6T_{11} \vee T_2T_3T_6T_{12} \vee T_2T_3T_4T_6T_{13} \vee \\
\vee T_2T_7T_{12} \vee T_2T_3T_7T_{13} \vdash T_9; \\
\overline{T_2T_6T_{11} \vee T_2T_3T_6T_{12} \vee T_2T_3T_4T_6T_{13}} \wedge \\
\wedge \overline{T_2T_7T_{12} \vee T_2T_3T_7T_{13}} T_9 \tau_3 \vdash \bar{T}_9; \\
\overline{T_2T_6T_{11} \vee T_2T_3T_6T_{12} \vee T_2T_3T_4T_6T_{13}} \wedge \\
\wedge \overline{T_2T_7T_{12} \vee T_2T_3T_7T_{13}} T_9 \tau_3 \vee \\
\vee R \vdash \bar{T}_2\bar{T}_3\bar{T}_4\bar{T}_5\bar{T}_6\bar{T}_7\bar{T}_{10}\bar{T}_{11}\bar{T}_{12}\bar{T}_{13}.
\end{array}
\right. \qquad (9)
$$

Let's transform the minimized sequential expressions into the structural scheme taking into consideration an industrial elemental base. As a result, we'll get the structural scheme of the device for controlling the discharger's working resource, shown on Fig. 2.

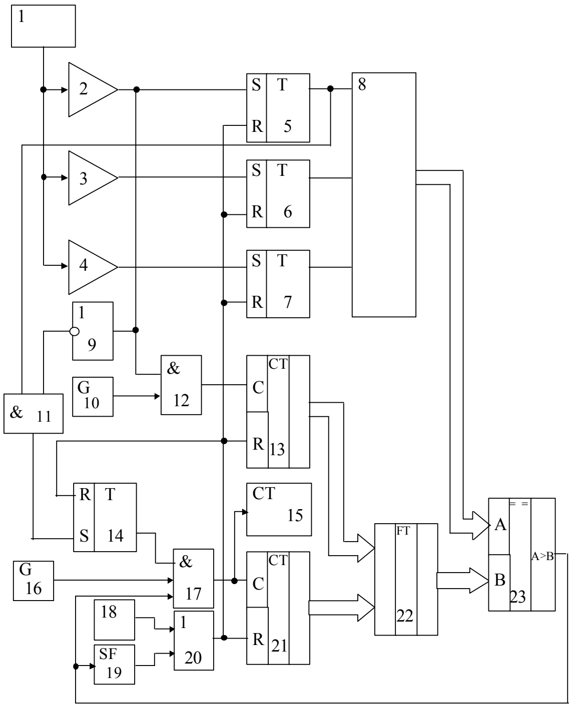

Fig. 2. Structural diagram of the device for the control of the working resource of dischargers

On the scheme: 1 – current sensor, 2,3,4 – comparator circuits, 5,6,7 – triggers, 8 – scrambler, 9 – NOT element, 10 – impulses' generator, 11, 12 – AND elements, 13 – impulse register, 14 – trigger, 15 – impulse counter, 16 – impulse generator, 17 – AND element, 18 – reset block, 19 – the signal former, 20 – OR element, 21 – impulses' counter, 22 – functional transformer, 23 – digital comparator circuit.

The suggested device works in the following way. When applying voltage to the circuit, the reset block 18 forms a short impulse, which sets all the triggers and impulse counters 13 and 21 into the original state. Impulse generators 10 and 16 begin to form the corresponding succession of impulses.

If the discharger comes into action, then the current, which passes through it, is fixed with the help of the current sensor 1 in analog-digital converter (ADC), which is made on the base of 2 – 8 elements. At the same time, when the comparator 2 comes into action, the signal of logical «1» is supplied on the AND element 12, from the output of which the succession of impulses' from an impulse generator 10 enters the impulse counter 13, where the length of the current wave is recorded as the digital code.

The impulse register 15 contains the initial value of the commutation resource of the discharger in terms of the accepted minimal value of the commutated current.

After the discharger's work is over under the appearance of the signal of logical zero on the output of the comparator 2, an AND element 11 is opened, trigger 14 comes into action and opens an AND element 17, and the impulses from the impulse generator 16 enter the impulse counter 21 till its output digital code, which is supplied to the input of the functional transformer 22, causes on its output an appearance of the digital code, which is supplied to the B-input of the digital comparator 23 and it coincides with the code, which is supplied to the A-input from the output of ADC. In addition, the signal of the logical zero is set on the output of the digital comparator 23 and an impulse supplying into the impulse counter 21 is over. At the same time, on the output of the signal former there appears a short impulse, which zero fills all the triggers and impulse counters 13 and 21. The work cycle is finished.

Within the period of the device operation the impulses from the impulse generator 16 also enter the resource impulse counter 15, which causes the reduction of the registered in this counter code by the certain number of units, which answer the depletion of the discharger's working resource taking into consideration the value of the commutated by the discharger current in terms of the minimal chosen value of the commutated current. The factors of the converting of the commutated current into the minimal value of this current are recorded in functional transformer 22, and the choice between this or that set of these factors is realized by output code of impulse counter 13, the value of which depends on the length of the current wave of the discharger.

It's obvious, that such a device is possible to realize in microprocessor execution also.

4. CONCLUSIONS

The suggested mathematical model allows to determine the residual working resource of the discharger with an accuracy within one commutation of the minimal chosen value of the current. The device for determination of the residual working resource of the dischargers, which is realized in accordance to suggested mathematical model with the usage of the sequence's mathematical tool, allows to automate the process of controlling the technical state of dischargers.

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