Computer Model of Thyratron TGI1-270/12

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Abstract: - The issues of developing the computer model of a thyratron - an electronic tube triode operating in a switching mode - are considered. A detailed description of the composition of the model is given. The computer model of a single-grid thyratron was developed in the form of a hierarchical block by means of OrCAD. The test circuit for the computer model of a thyratron is suggested. The simulation results of the test circuit operation including a thyratron model are presented (simulated currents and voltages, dynamic characteristics of the thyratron - anode current as a function of the grid voltage). The computer model demonstrated adequacy to the product data sheet.

Key-Words: - thyratron, computer model, simulation, pulse voltage, OrCAD, test circuit

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1 Introduction

In the technological chain of production of traction electric machines, there is a place for testing electrical insulation with pulsed voltage. Pulse repeatability 50 times per second for up to 60 seconds. In some tests, the pulse amplitude can reach 16–20 kV, [1]. In connection with the increasing use of static converters with a pulsed voltage form on railway rolling stock, testing with pulsed voltage with a frequency much higher than the industrial one is possible.

2 Problem Formulation

Often, a pulse voltage generator is built based on a thyratron, [1] - a tube triode with a specific dynamic characteristic - in the thyratron, from the moment of ignition, the anode current avalanche-like reaches the saturation current value and then does not depend on the voltage on the grid, [2], [3]. Compared to semi-conductor switches, a thyratron has advantages: the absence of leakage currents in a non-conducting state, and an extremely short recovery time for the electrical strength of the switch after switching pulse power (units of microseconds), [4]. An urgent task in developing pulse voltage test benches is reliable computer modeling, which in turn poses the task of developing a computer model (CM) of the thyratron. An example of solving such a problem for the TGI1-270/12 thyratron using OrCAD - one of the modern widely used tools for the simulation electronic and electrical circuits and devices, [5] - is given in this article.

The appearance of the modeling object, that is, the TGI1-270/12 type thyratron, is shown in Figure 1.

Fig. 1: Appearance of the TGI1-270/12 thyratron

3 Problem Solution

The CM of a single-grid thyratron was developed in the form of a hierarchical block, [5] based on materials, [2], [3], [6], [7], [8]. The author, unfortunately, was unable to find in published sources, [2], [3], [4], [9], [10], [11], [12], a system of differential equations describing the physical processes occurring in the thyratron, which could simplify the structure of the CM. Issues of cathode heating in CM were not considered. The test circuit for testing the CM thyratron is shown in Figure 2. The anode and cathode of the thyratron (bidirectional ports named *an* and *ca*), as well as the grid (unidirectional input port named *gr*), are used as ports of the hierarchical block, [4].

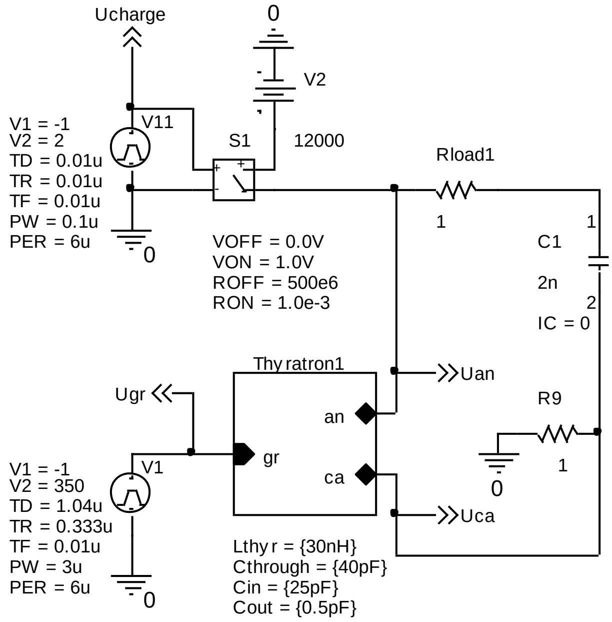

Fig. 2: The test circuit for the CM of a thyratron

As adjustable CM parameters "outside" the hierarchical block, those listed in Table 1 are displayed. Between the anode and cathode of the thyratron, a capacitance *C*1 with a rated value of 2 nF and a resistance *Rload*1 with a rated value of 1 Ohm are connected in series. The initial voltage on capacitor *C*1 is set equal to zero.

*C*1 is charged from a high (here 12 kV) DC voltage source *V*2 through *Rload*1 by turning on switch *S*1, controlled by a pulsed voltage source *V*11.

Further, when conditions sufficient for ignition of the thyratron are reached, a discharge of *C*1 occurs through *Rload*1, and the anode-cathode circuit of the thyratron continues until the thyratron is locked according to potential conditions on its main electrodes. The thyratron is quenched when the grid voltage has not yet been removed by reducing the anode-cathode voltage to 150 V. Then the whole cycle is repeated.

The structure of the hierarchical block is shown in Figure 3. In the anode-cathode circuit, the following are connected in series: a voltage-controlled switch; inductance *Lthyr*; and a diode that ensures unidirectional current from the anode to the cathode. For the diode, the *Dbreak* element was used, [5], in which the active resistance Rs is minimized to reduce the influence on the parameters of the thyratron (*Rs* = 0.00001 Ohm is assumed). The inductance-switch circuit is shunted by a *Cthrough* capacitor.

Table 1. Customizable parameters of the thyratron CM

Designation	Parameter name	Parameter value	References
Lthyr	self-inductance of the thyratron	20…30 nH	[6] (according to data from the TDI1-150k/25 thyratron)
Cthrough	thyratron feedthrough capacity (anode-cathode capacity)	40 pF	[7] (according to data from the TGI1-700/25 thyratron)
Cin	input capacitance of the thyratron (capacitance anode - ground)	40 pF	[7] (according to data from the TGI1-700/25 thyratron)
Cout	output capacitance of the thyratron (capacitance cathode - ground)	0.5 pF	[7] (according to data from the TGI1-700/25 thyratron)

Note that the resistance of the voltage-controlled switch (element *S*, [5]) changes from *Ron* to *Roff* while the control voltage changes from *Von* to *Voff* and vice versa. A voltage-controlled switch turns off when a voltage signal of less than 150 V is applied to its control. This occurs, for example, when the anode-cathode voltage polarity changes or the anode-cathode voltage decreases to a value less than the anode ignition voltage.

To adjust the turning on and turning off time moments of the switch, a table-type nonlinearity is used, implemented on the *TABLE* element, [5], the input of which is supplied with a signal of the potential difference between the anode and the cathode. The output signal of the *TABLE* element is multiplied by the pre-processed grid potential value. In our case, only "-1" and "1" are used as output values of the *TABLE* element: one corresponds to a voltage at the anode of at least 150 V.

The switch closure voltage is selected in such a way that closure occurs only when the anode-cathode voltage is positive and the grid voltage is not less than the minimum required for ignition.

As a signal of the ignition voltage of the grid in the developed CM, not the signal u_{gr} itself is used, but a processed signal $u_{gr0} = u_{gr} + u_{Cout0}$, where u_{Cout0} – the sum of the voltage u_{Cout} between the plates of the capacitor *Cout* and the DC bias voltage, limited to 0...1000 V.

The DC bias voltage is set to 2000 V, which is taken from the u_{Cout} simulation results of the circuit in Figure 4 during 1.4 ms. When shortening the u_{gr} pulse duration, a higher bias voltage (over 5000 V) may be required. According to the technical data of the TGI1-270/12 thyratron, the duration of the ignition pulse u_{gr} lies in the range of 3 – 5 µs, [8].

In the computer model of the thyratron shown in Figure 3, several functional blocks are used, the purpose of which requires a separate explanation.

Block 1. Nonlinear transfer function. The value of the potential difference between the anode and cathode of the thyratron.

Block 2. Nonlinear transfer function. If the current in the anode - cathode circuit is less than 0.01 A, then the output value is “0”, otherwise the output value is “1”. The current value of 0.01 A is much less than the current flowing in the anode-cathode circuit at a voltage between these thyratron electrodes of 150 V. Multiplying the signal from the output of block 3 by the output signal of block 2 ensures that the thyratron is extinguished at a low current in the anode-cathode circuit.

Block 3. Nonlinear transfer function. If the voltage between the anode and cathode increases, then the output value is “-1”, otherwise “1”. The signal ensures that the thyratron is kept burning, that is, the switch is in an on state when the voltage of the anode-cathode circuit decreases. With increasing voltage in the anode-cathode circuit, for ignition and continuation of combustion, the product of the potential difference between the anode and cathode (at least 2000 V) and the grid voltage (at least 300 V) is sufficient, provided that each signal has a positive sign. The fact of an increase in voltage between the anode and cathode is determined by the value of the derivative of this voltage. Here, it is assumed that the voltage increases if the value of its derivative exceeds 1000. A zero derivative threshold value was not used to avoid the output signal of block 3 bouncing near zero.

Block 4. Nonlinear transfer function. If the grid voltage is less than 300 V, then the output value is “0”, otherwise “1”. Multiplying the output signal of block 4 by the grid voltage prohibits turning on the switch, that is, turning on the thyratron until the grid voltage reaches the value of the ignition pulse.

Block 5. Constant voltage source. Generates a voltage (here the value taken is 2000 V) that ensures combustion of the thyratron, that is, the flow of current in the anode-cathode circuit by maintaining a fictitious anode voltage of at least 2000 V in conditions where the actual voltage of the anode-cathode circuit is less than 2000 V, but more than 150 V.

Block 6. Limiter that prevents the passage of a negative signal from the output of block 6 to the input of block 8 with a positive voltage of the anode-cathode circuit greater than 2000 V.

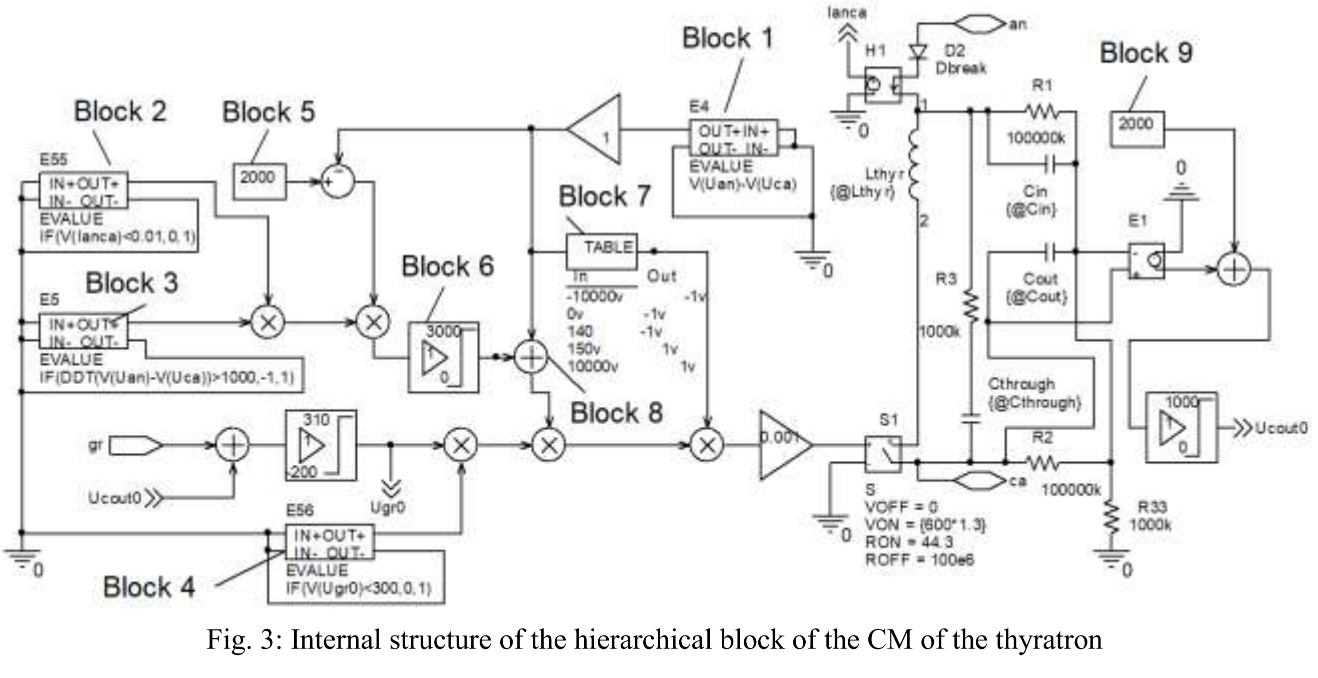

Fig. 3: Internal structure of the hierarchical block of the CM of the thyratron

Block 7. Tabular assignment of the transfer function. Sets the type of nonlinear dependence that ensures the extinction of the thyratron, that is, interruption of the current in the anode-cathode circuit when the anode-cathode voltage decreases to less than 150 V. Multiplication by the output signal of block 7 ensures that the switch is turned off when the anode-cathode voltage is less than 150 V.

Block 8. Sum. Multiplying by the output signal of block 8 provides a fictitious anode voltage value sufficient to maintain the thyratron combustion if the thyratron is already ignited, and the anode-cathode voltage value is less than 2000 V, but more than 150 V. That is, the switch is kept “on”.

Block 9. Constant voltage source. Generates a bias voltage (here assumed to be 2000 V). In general, the value of the bias voltage depends on the duration of the ignition pulse: as the pulse duration decreases, the value of the bias voltage increases.

The results of computer simulation for the test circuit (Figure 2) are shown in Figure 4, Figure 5, Figure 6, Figure 7 and Figure 8. The maximum time step is assumed to be 1 ns.

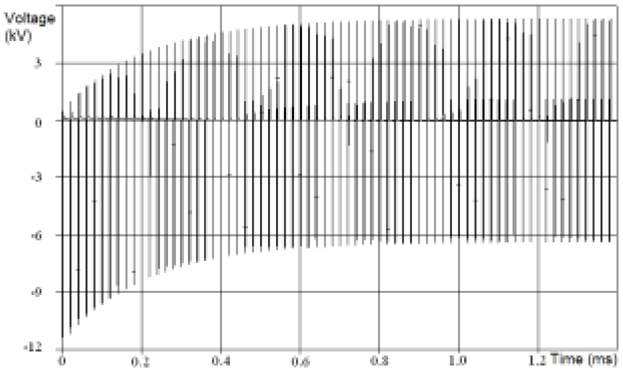

Fig. 4: Simulation results for the test circuit in Figure 2. The transition process of u_{Cout}

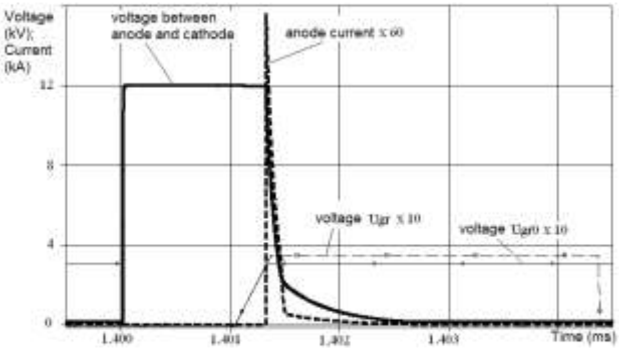

Fig. 5: Simulation results for the test circuit in Figure 2. Currents and voltages of the thyratron during the formation of a high voltage pulse

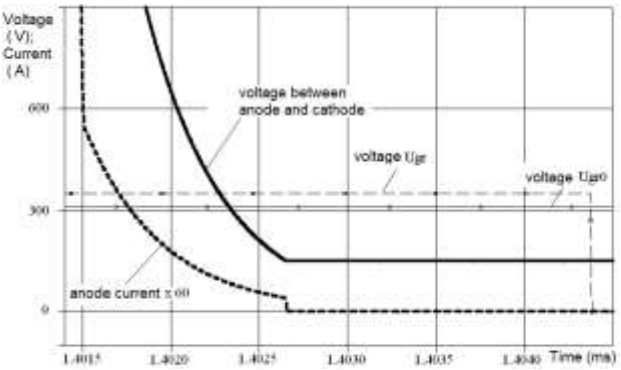

Fig. 6: Simulation results for the test circuit in Figure 2. Currents and voltages during thyratron quenching

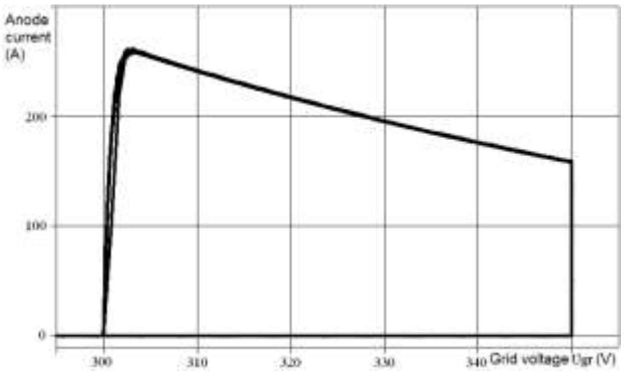

Fig. 7: Simulation results for the test circuit in Figure 2. Dynamic characteristics of a thyratron: anode current as a function of the u_{gr} signal

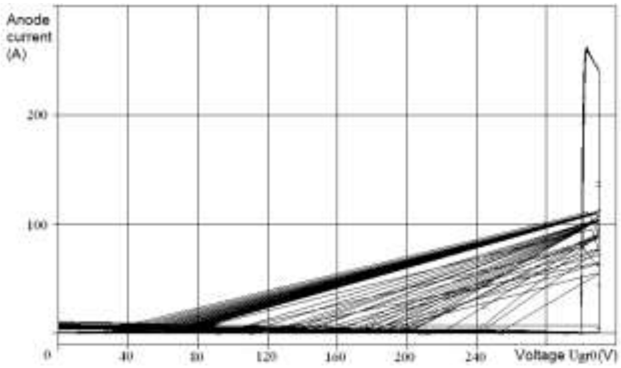

Fig. 8: Simulation results for the test circuit in Figure 2. Dynamic characteristics of a thyratron: anode current as a function of the u_{gr0} signal

4 Conclusion

From Figure 5, Figure 7 and Figure 8 there is a good correspondence of the maximum value of the anode pulse current, simulated by the CM, indicated in the product data sheet, [8].

Thus, a software tool (CM of the TGI1-270/12 thyratron) has been developed, suitable for constructing more complex CM of electrical and electronic circuits and devices to simulate their operating modes.

References:

[1] V.I. Bocharov, A.I. Kargin, K.V. Kolokolov, *Mainline electric locomotives: Technological basis of production*, Moscow, Mechanical Engineering, 1992, pp. 256.

[2] A.V. Akimov, P.V. Logachev, V.D. Bochkov, D.V. Bochkov, V.M. Dyagilev, V.G. Ushich, Application of TPI-thyratrons in a Double-pulse Mode Power Modulator with Inductive-resistive Load, *IEEE Transactions on Dielectrics and Electrical Insulation*, Vol. 17, Iss. 3, 2010, pp. 718-722.

[3] Thyratron Working Principle, [Online]. https://www.eeeguide.com/thyratron-working-principle/ (Accessed Date: March 20, 2024).

[4] P.P. Gugin, Application of the TPI1-10k/50 thyratron in a frequency mode for pumping gas lasers, *Instrum Exp. Tech.* Vol. 56, 2013, pp. 325–328. doi: 10.1134/S0020441213020073.

[5] J. Keown, *OrCAD PSpice and Circuit Analysis, 4th edition*, Prentice Hall, 2000.

[6] V.D. Bochkov, D.V. Botchkov, V.M. Dyagilev, V.N. Kudinov, V.G. Ushich, V.A. Glouschenkov, R.Yu. Yusupov, High power pseudospark switches for pulsed power, *Conference Record of the Twenty-Fifth International Power Modulator Symposium, 2002 and 2002 High-Voltage Workshop., Hollywood, CA, USA*, 2002, pp. 475-478. doi: 10.1109/MODSYM.2002.1189518.

[7] Thyratron TGI1-700/25, [Online]. http://www.155la3.ru/datafiles/tgi1_700_25.pdf (Accessed Date: March 20, 2024).

[8] Pulse modulator thyratron TGI1-270/12, [Online]. http://www.155la3.ru/datafiles/tgi1_270_12_tu_1976.pdf (Accessed Date: March 20, 2024).

[9] Hooman Mohammadi Moghadam, Kasra ghobadi, Asadollah Taghavi kolaei, Design and Simulation of Thyratron Switch Using for Pulse Forming Network, *4th National Conference on Applied Research in Electrical and Computer Science and Medical Engineering*, *Shirvan*, 2020, [Online]. https://www.researchgate.net/publication/342814297_Design_and_Simulation_of_Thyratron_Switch_Using_for_Pulse_Forming_Network (Accessed Date: March 20, 2024).

[10] Yan Jiaqi, Shen Saikang, Sun Guoxiang, Ding Weidong, Review on Physical Mechanisms and Applications of Pseudospark Discharge, *Transactions of China Electrotechnical Society*, Vol.36, No. 11, 2021, pp. 2408–2423. doi: 10.19595/j.cnki.1000-6753.tces.200262

[11] N.V. Landl, Y.D. Korolev, O.B. Frants, V.G. Geyman, A.V. Bolotov, Low-Current Hollow-Cathode Discharge in a Trigger Unit of a Cold Cathode Thyratron, *Journal of Physics: Conference Series*, Vol. 652, 2015. doi: 10.1088/1742-6596/652/1/012050

[12] V.D. Bochkov, D.V. Bochkov, I.N. Gnedin, G.M. Vasiliev, V.A. Vasetskiy, S.A. Zhdanok, High voltage pulse generator based on TPI-thyratron for pulsed electric field milk processing, *2012 IEEE International Power Modulator and High Voltage Conference (IPMHVC), San Diego, CA, USA*, 2012, pp. 98-101. doi: 10.1109/IPMHVC.2012.6518689

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Conflict of Interest

The author has no conflicts of interest to declare.