

METHODOLOGICAL ASPECTS OF DIGITAL MODELS BUILDUP AT THE CONTROL SYSTEMS DESIGN

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Introduction. Currently, the use of mathematical modeling has become a widespread and effective means of developing electronic technology. Mathematical modeling in recent decades has developed into a separate interdisciplinary field of knowledge with its inherent objects, approaches and research methods. As a rule, in the works of this direction, the main attention is paid to the methods of research of mathematical models themselves, qualitative analysis of solutions, new effects in the processes and phenomena under study [1].

Only a thorough knowledge of the modeling object of the relevant subject area, as well as the ability to speak the same language with the model's customer specialists, allows us to hope for the successful implementation of a project to create a mathematical model of a process or phenomenon [1].

The status of the issue. Traditionally, the main part of the quantitative information necessary for making a final decision (both in terms of the degree of detail and the level of reliability) was formed at the stage of experimental testing of technical devices. As they become more complicated and more expensive, as well as the lengthening of the stage of their experimental development, the significance of design calculations began to grow, there was a need to increase the reliability of such calculations, providing a more reasonable screening out of alternative solutions at the initial stage of design and a refined formulation of quantitative criteria for structural and parametric optimization [2].

The rapid development of knowledge-intensive industries, which should include modern shipbuilding and instrumentation, has led to further complication of the developed and operated technical devices and systems. Their experimental development began to require more and more time and material resources, and in some cases the growing costs turned into a problem that does not have an acceptable direct solution [2].

Relevance. Under these conditions, the value of the computational and theoretical analysis of the characteristics of such devices and systems has significantly increased. This was also facilitated by a breakthrough in the improvement of computer technology, which led to the emergence of modern computers with a large amount of memory and high speed of performing arithmetic operations. As a result, there was a material base for the formation and rapid development of mathematical modeling, there were real prerequisites for using a computational experiment not only as a computational and theoretical support at the stage of testing a technical device, but also during its design, selection and optimization of its operational modes, analysis of its reliability and prediction of failures, emergencies, and also, when evaluating the possibilities of boosting the characteristics and upgrading the technical device [3].

The history of the issue. Certain prerequisites for the widespread use of mathematical modeling and computational experiment in engineering were created thanks to the development of analog modeling methods. The basis of most of these methods was the use of analog electrical models for the study of processes in mechanical, thermal and hydraulic systems. Phenomena are considered mathematically analogous if they are described by equations of the same form. The mathematical analogy between processes in electrical circuits and other physical phenomena makes it possible to create modeling installations, which, in essence, are specialized analog computing machines (AVMs) [4].

Currently, mathematical modeling and computational experiment using computers have become integral parts of common approaches characteristic of modern information technologies. No less important is the fact that modern means of displaying information make it possible to conduct a dialogue with a computer, that is, to analyze alternative approaches, check assumptions, experiment with a mathematical model [1, 3, 4].

The practical implementation of the possibilities of mathematical modeling and numerical experiment significantly increase the efficiency of engineering work, especially when creating fundamentally new control systems and devices that do not have prototypes, which reduces the time and money spent on the use of advanced achievements in physics, electrical engineering, mechanics and other fundamental sciences. The noted possibilities of mathematical modeling and computational experiment are far from being exhausted, they seem quite promising and therefore deserve detailed consideration [1, 4].

It is advisable to start working in the field of mathematical modeling with the simplest models illustrating the basic laws of control, and then gradually increase the complexity by introducing additional factors [1].

Implementation of digital models on the example of design in JSC «NPF «Meridian». The use of digital models and mathematical modeling in the development of almost all production systems is widely used in JSC «NPF «Meridian». To model their own systems, enterprise developers use software packages such as MultiSim, MicroCap, Proteus, MatLab/Simulink. The MicroCap program has become more widespread due to its convenient and intuitive interface, extensive element base, built-in tools for working with a digital model. As an example, the construction of a digital model of a static converter of a shipboard automatic magnetic field compensation system for hull structures is described [5].

The construction of a digital model is carried out, as a rule, simultaneously with mathematical modeling, which complement each other at each stage. Since most static converters use a transistor bridge circuit, it is advisable to start with the development of a bridge circuit model, an example of which is shown in Fig. 1. This model is simplified and is made on elements that do not include complex mathematical actions and operators [5, 1].

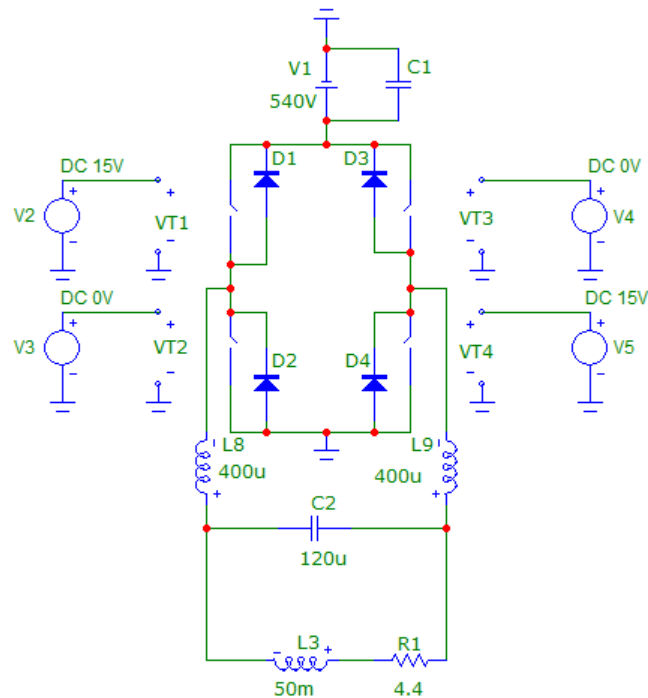


Fig. 1. Model of a transistor bridge circuit in the MicroCap program

Transistors VT1-VT4 are replaced by switches controlled by the voltage at the input of the switch. The supply voltage is modeled by the power supply V1, and the control signals are simulated by voltage sources V2-V5, which allow generating signals of various shapes (DC voltage, sinusoidal, triangular, pulse, exponential, piecewise linear, etc.). Also, the model contains such passive elements as resistors, capacitors, chokes, which, thanks to the mathematical apparatus embedded in them, behave like components close to reality with a certain degree of assumption. It is worth noting that MicroCap libraries have elements that have mass-produced prototypes, as well as elements that are only mathematical operators [1].

Verification of the model should begin with the supply of control signals of constant voltage from sources V2-V5, in which it is enough to simply calculate the voltage and current in the load R1. Thus, the adequacy of the behavior of the model is checked [5].

In any program for performing digital models, a very important point is the ability to display the simulation results. The MicroCap program has one of the most convenient means of displaying modeling results. If the work is carried out with constant voltages, it is convenient to call the "Dynamic DC DC Analysis" function, which allows you to determine voltages, currents and current directions at any point of the circuit in real time, as shown in Fig. 2, which saves the developer from significant time costs for calculating DC modes current. For example, if the voltage value of the power supply V1 is changed, then changes in the values of currents and voltages are immediately reflected on the digital model [5].

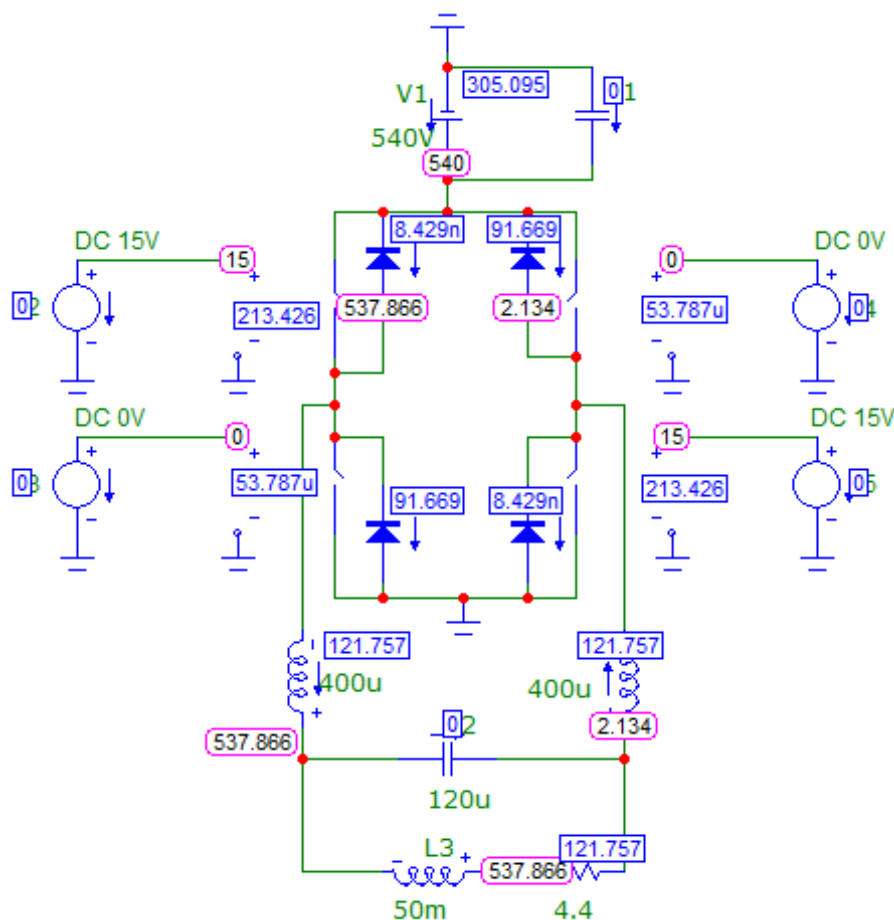


Fig. 2. Displaying information about electrical characteristics

Another positive aspect of the MicroCap program is the possibility of adding animation blocks to the digital model, thanks to which it becomes possible to control the model more quickly, as shown in Fig. 3. As part of the digital model, there are connectors S1-S4, which can be installed in a conductive or disconnected state with a simple mouse click, which in many cases allows for more rapid experiments with the model. The model also uses the Meter1 voltage indicator, which shows the potential difference between two selected points in real time. Such a voltage indicator is an informative tool for the operational analysis of the result, since in the «Dynamic DC DC Analysis» mode, voltage values are displayed exclusively relative to the general circuit current. Any tool of the program is useful for the developer, which will speed up the creation of a model that is close in its properties and functions to a real product [5, 4].

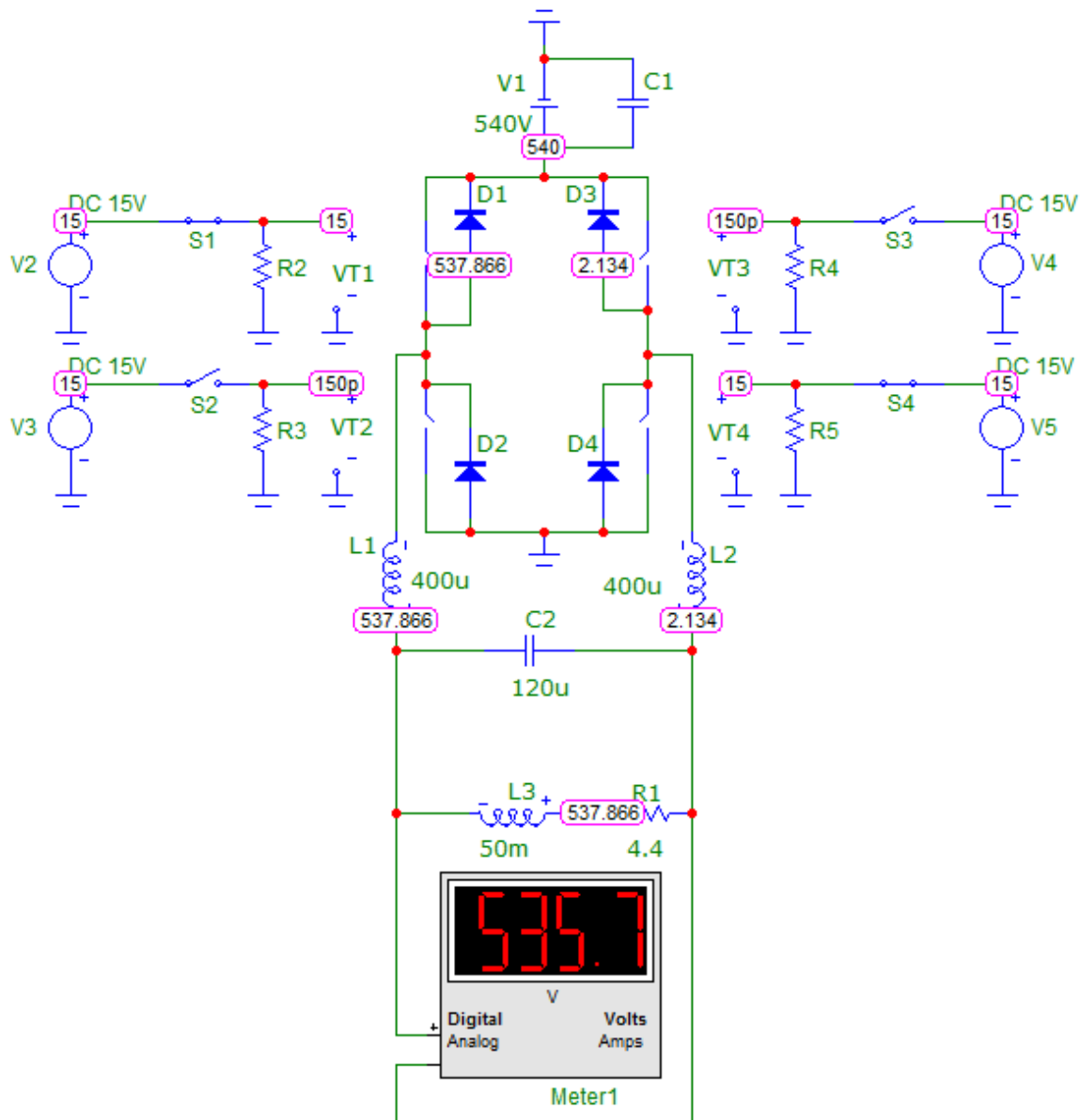


Fig. 3. Digital model with animations

If the behavior of the simplified digital model in different modes corresponds to the ideas about the operation of the circuit contained in the specialist, then you can start to

complicate the model in order to gradually bring it to maximum compliance with the real product [4].

The real transistor bridge circuit operates in pulse mode, so the control voltage sources must be switched to pulse mode, as shown in Fig. 4 [5].

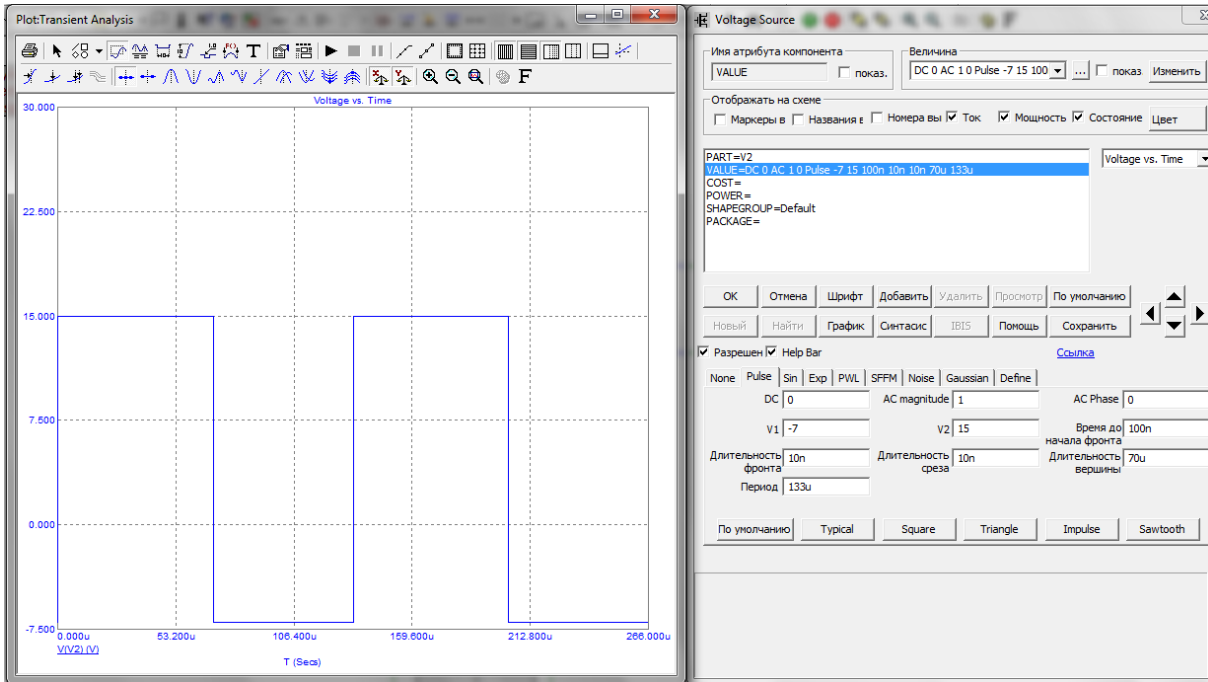


Fig. 4. Setting up the control voltage source

In the above case, the control sources V1 and V4 are tuned to the control pulse frequency of 7.5 kHz (an acceptable switching frequency for domestic IGBT transistors). The voltage amplitude from minus 7 V to plus 15 V is characteristic of the operation of the control drivers, and the control sources simulate the operation of the control drivers. In order for the value of the pulse signal frequency to be 7.5 kHz, we select the value of the period T of the control signal of 133 microseconds ($T=1/(7.5 \cdot 10^3)=133 \text{ iss}$). The pulse duration of the pulse (vertex) t is 70 microseconds.

From here you can calculate the pulse fill factor

$$D = \frac{t}{T} = \frac{70 \cdot 10^3}{133 \cdot 10^3} \approx 0.526$$

Accordingly, now we can determine the voltage on the load R1

$$U_{R1} = U_{out} \cdot D = 535.7 \cdot 0.526 = 281.95 \text{ B}$$

Further, in the MicroCap program, it is possible to compare the results of the computational calculation and the digital model. When working with pulsed voltage, you cannot use the «Dynamic DC DC Analysis» option, since it provides correct data only when working with constant voltages and currents. For the pulse voltage mode, the MicroCap program provides for displaying the results when working with arbitrary-shaped signals. To do this, the "Transient Analysis Transient" mode is used, shown in Fig. 5. In the «Time Range» column, the time duration of the waveform is set. Count "Max. the time step" corresponds to the sampling step of the microcontroller that will be used in a real device, so it is desirable that they are the same [5].

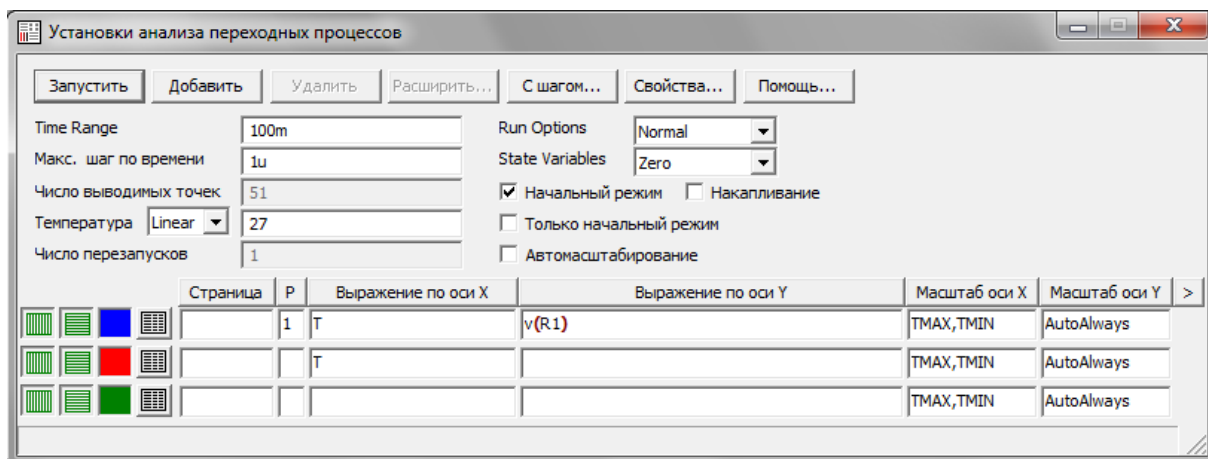


Fig. 5. Installation window for transient analysis

Looking at the received oscillogram of the load voltage R1 according to Fig. 6, it is not difficult to notice that the received voltage in steady-state mode is 287.5 V, which differs from the calculated one by 1.9%. For the development of a digital model, such a discrepancy is within the limits of engineering accuracy and is acceptable [5].

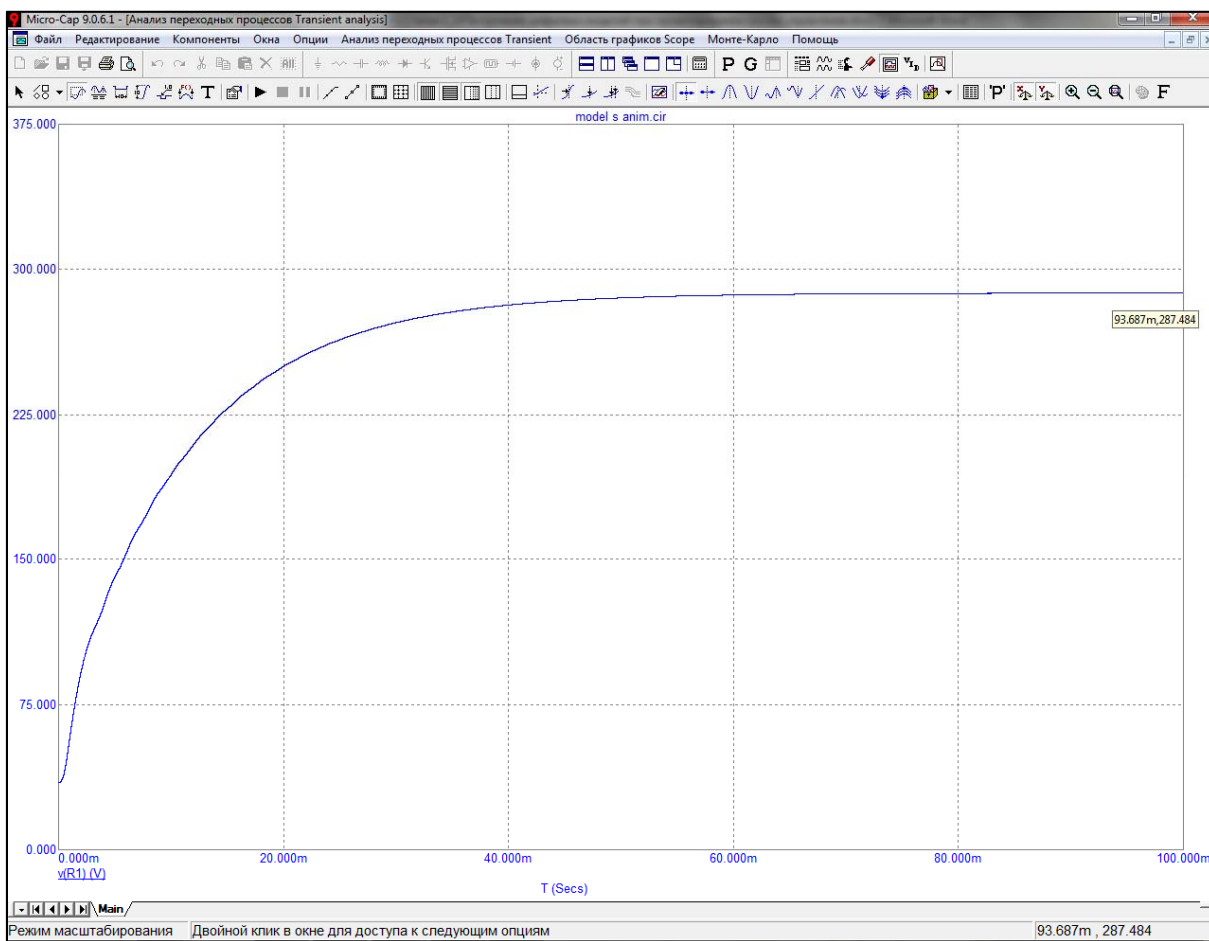


Fig. 6. Voltage waveform at load R1

The next step in complicating the digital model is to add the possibility of operation of a transistor bridge circuit in various modes. This complication is carried out due to analog multiplexers ADG409, a model of which is also available in MicroCap [5].

The analog multiplexers shown in Fig. 7 have multiple inputs and one output. Depending on the control signals A0 and A1, one of the inputs of the multiplexer is connected to the output, skipping the selected control signal. This complication is introduced due to the fact that there are various options for supplying control signals to transistor gates [5].

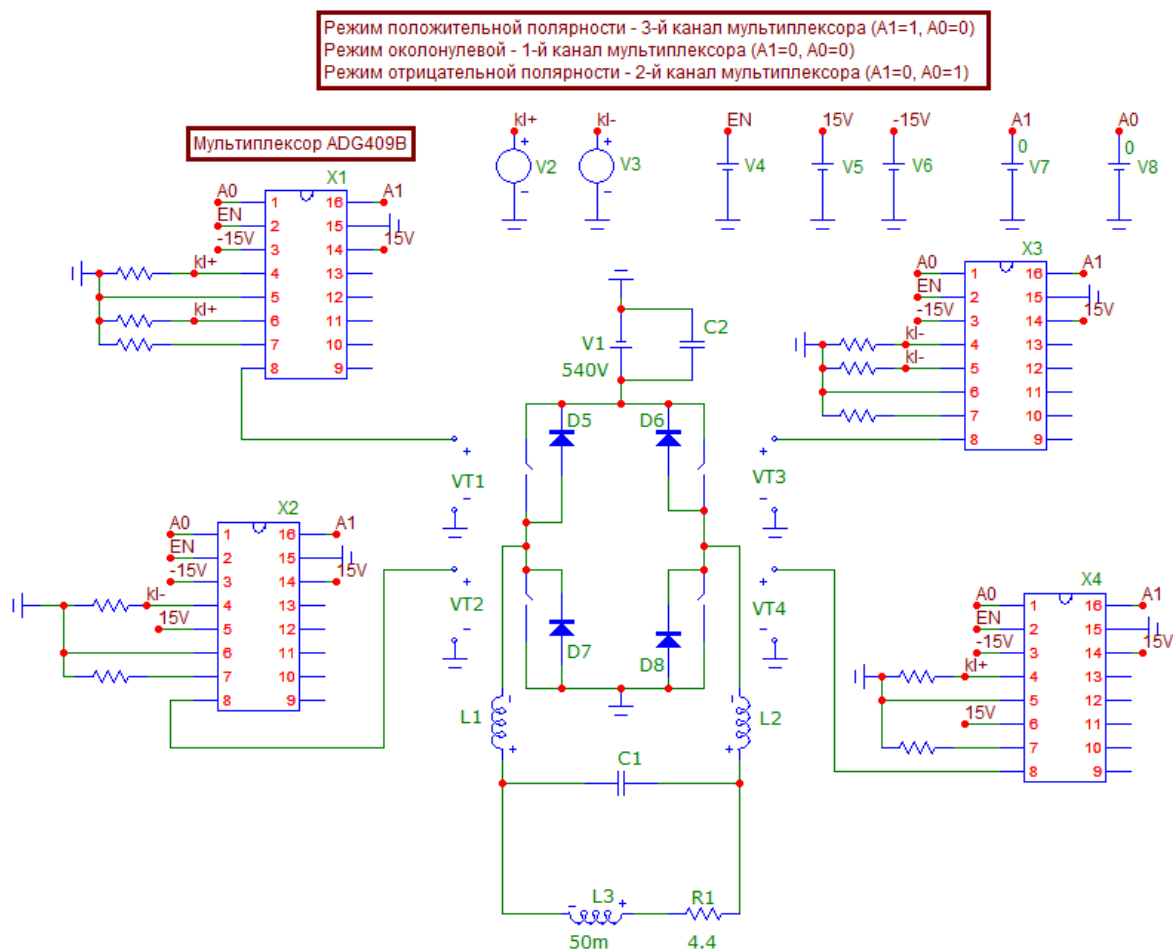


Fig. 7. Digital model of a bridge circuit with switching via multiplexers

The model constructed at this stage generates control pulses through control sources, in the menu of which the necessary signal parameters are set. But in a real product, a signal generator is used with the ability to adjust the duty cycle of control pulses [5].

Fig. 8 shows a modified model that allows the formation of three types of sawtooth signals due to a sawtooth voltage generator (cascades X3 and X4) and two differential amplifiers (cascades X5 and X6). The control signal, which is simulated by the voltage source V1, passes through the differential amplifier (cascade X1) and enters the comparator (cascade X2), where it is compared with the selected sawtooth voltage. As a result, pulses with an adjustable duty cycle are formed at the output of the X2 cascade, which is the result of comparing the sawtooth signal and the control signal at the comparator inputs. Thus, the model is enhanced by the ability to adjust the current and voltage at load R1 [5].

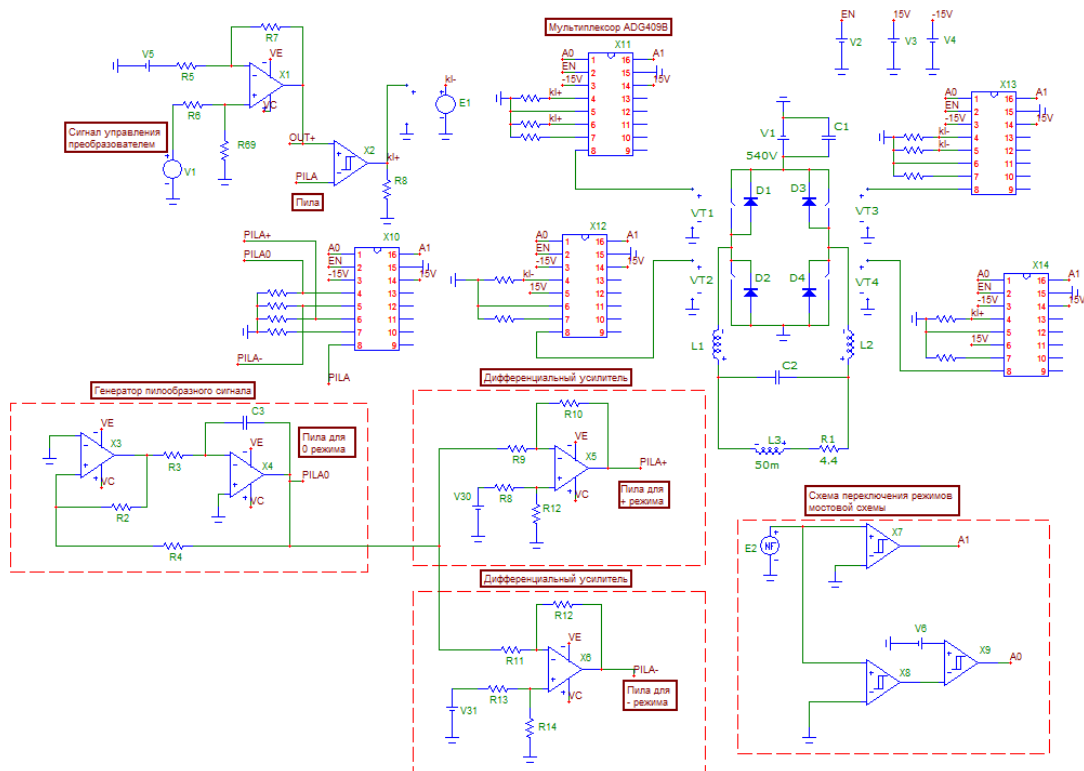


Fig. 8. Digital model of a static converter without current feedback

The last stage of complicating the digital model is the introduction of feedback, which ensures the stability of the system, and the PID controller, which provides the necessary accuracy of processing the control signal, as shown in Fig. 9 [5].

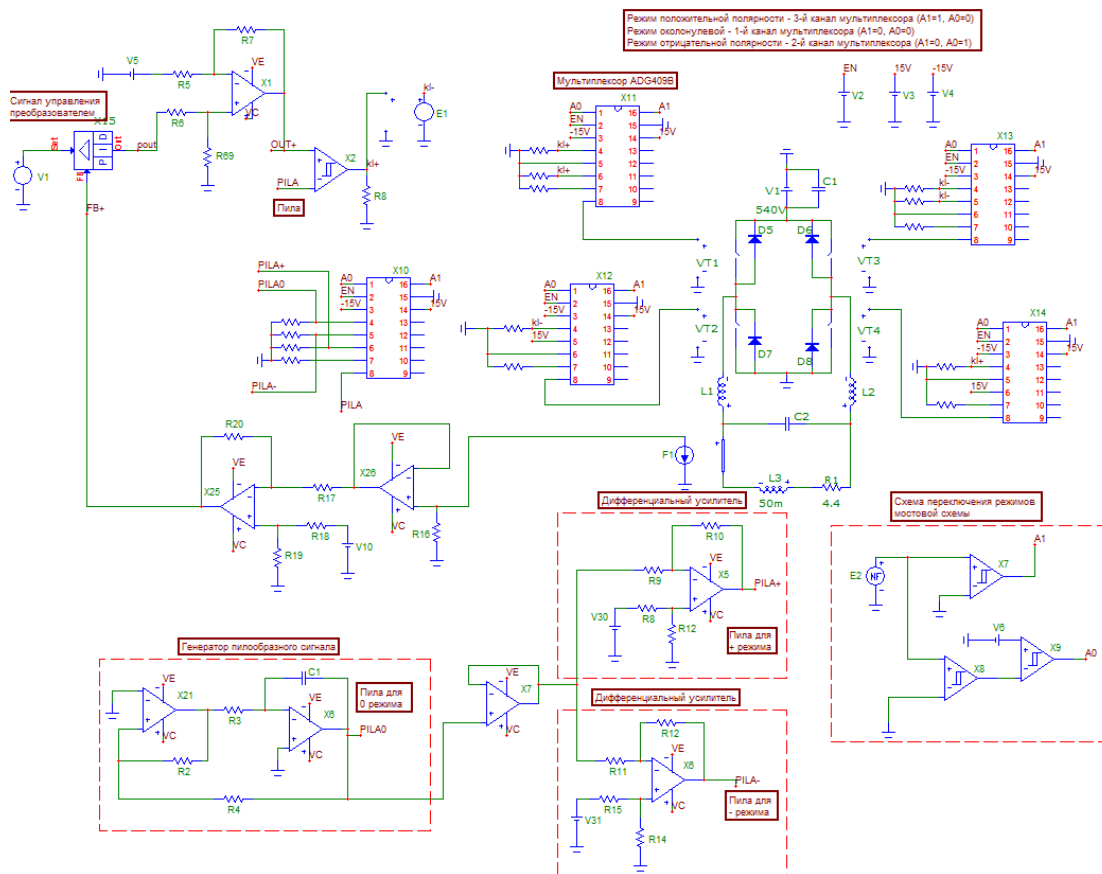


Fig. 9. Digital model of a static converter with current feedback

A transfer link F1 has been added to the load circuit of the resistor R1, which simulates a current sensor. The feedback signal from the F1 sensor via the level offset circuit (cascade X25) is sent to the FB+ feedback output of the PID controller. If the current in the load R1 does not correspond to the control signal coming from the source V1, then the PID controller changes the signal at its output until the current in the load R1 comes into line with the control signal [5].

Conclusion

This article shows only the general principles of the methodology for creating and testing a digital model of an electronic control system. The instrumentation of circuit modeling programs allows analyzing the operation of the model not only in the time domain, but also in the frequency domain, modeling the operation under the influence of components' own noise, numerically evaluating the stability of the parameters with a random deviation of the nominal values within the specified normalized start-ups, with a change in ambient temperature. The general methodology for creating and testing a digital model of an electronic control system is the need for active interaction between the developer and the modeling environment. Working out the digital model in the "from simple to complex" mode, at each step of the iteration, the developer must carefully evaluate the result obtained. In other words, the electronic model allows you to change the operating modes, add and disable elements by very simple means. It is basically impossible to disable an electronic circuit due to an error or careless action, as it can happen when working with a physical device [1, 2, 3].

The use of mathematical modeling in JSC «NPF «Meridian» during the development of control systems allowed to reduce financial and time costs for physical prototyping by up to 50%, to check physical devices only in the most critical and complex cases, and for less complex devices to limit themselves only to mathematical models before launching into serial production.

Resources

1. Introduction to mathematical modeling: Textbook / Edited by P.V. Trusova. M.: Logos, 2005. 440 p.
2. **Vanko V.I.** Variational calculus and optimal control: Textbook for universities. Rec. MO/ O.V. Ermoshina, G.N. Kuvyrkin. Edited by V.S. Zarubin, A.P. Krishchenko. 2nd ed. Moscow: MSTU Publishing House, 2001. 488 p.
3. **Malinetsky G.G.** Chaos. Structures. Computational experiment: Introduction to nonlinear dynamics. M.: Publishing House of the URSS, 2002. 256 p.
4. **Emelyanov A.A.** The path from analog models to a simulator on a digital computer. // Applied Computer Science. 2007. No. 5. Pp. 41–53.
5. **Amelina M.A., Amelin S.A.** Micro-Cap circuit modeling program. Versions 9, 10. Smolensk, Smolensk branch of NRU MEI, 2012. 617 p.