Mathematical logic as a mean of solving the problems of power supply for buildings and constructions

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Abstract. The article analyzes the questions of application of mathematical logic in engineering design associated with machinery and construction. The aim of the work is to study the logical working-out of Russian electrical engineer V.I. Shestakov. These elaborations are considered in connection with the problem of analysis and synthesis of relay contact circuits of the degenerate (A) class which the scientist solved. The article proposes to use Shestakov’s elaborations for optimization of buildings and constructions of modern high-tech. In the second part of the article the events are actualized in association with the development of problems of application of mathematical logic in the analysis and synthesis of electric circuits, relay and bridging. The arguments in favor of the priority of the authorship of the elaborations of Russian electrical engineer V. I. Shestakov, K. Shannon – one of the founders of computer science, and Japanese engineer A. Nakashima are discussed. The issue of contradiction between V. I. Shestakov and representatives of the school of M. A. Gavrilon is touched on.

1. Introduction

At present, the problem of power supply for buildings and constructions is being solved by introducing new energy-saving technologies. Builders-practitioners widely apply the achievements of modern high-tech, methods of energy-saving design. "Green light" is given to the use of new safe for human ecology materials. It is necessary to say that today much is being done in this direction. Electronic and now digital systems of urban management, as well as transport, are widely introduced into practice. Information technology has been developed in the management of transport and the park economy in the Russian capital. Information systems of social security have proved to be good. Similar systems work in education. The Mayor of the Russian capital S. Sobyanin noted the need to use the most modern energy solutions in the field of transport, parking, control of road traffic. The head of the executive power of Moscow stressed the need to optimize such systems.

However, the optimization of energy supply of buildings can be solved in a proven way through the use in the design the formal-logical schemes developed by mathematical logic. According to the authors, the use of such solutions will increase the effect of the introduction of new technologies. Indeed, the method of mathematical formalization seems to researchers to be highly reliable and widespread. It is emphasized, for example, that mathematical formalism has become common in modern applied and technical sciences and is perceived as something natural. In fact, we can talk
about the practical application of mathematical theories, which fill the limitations connected, for example, with a shortage of funds, defects in the production cycle, costs in training construction personnel, etc. In this paper, the authors consider the use of schemes of mathematical logic (algebra of logic) in the sphere of power supply for buildings and constructions. The article gives only the statement of such a vast issue. The optimization we indicated is especially important when creating the power supply schemes for so-called "smart houses" and even "smart cities" of the future. Further development of this problem will be reflected in following research by the authors. In the proposed article, the problem of the using of logic of relay contact circuits created by well-known Russian engineer V.I. Shestakov is being solved. Therefore, the object of the investigation will be the main provisions of the theory of logic of relay contact circuits, and the subject is the determination of the areas of use of this theory in the practice of power supply for buildings and constructions.

Defining the object of the paper, the authors rely on the findings of researchers of XX-XXI centuries.

The work takes into account the conclusions that are contained in the researches of representatives of both theoretical and applied disciplines, in the works of logicians, mathematicians and construction engineers, who considered various problems of applying mathematical logic in the sphere of urban design and urban planning. In particular, the use of the logic of fuzzy sets of the famous American mathematician of Azeri origin Asker Lotfi-Zade [1], for ecological expertise and planning of industrial development of the coastal zone of Ghana (African state) was considered by Slesarev M.U., Phyllis T. et al. [2] [3] (for some aspects of the application of the logic of fuzzy sets of Lotfi-Zade, see [4]). In their works, the concrete results of the application of indefinite logic (the logic of undetermined values) are represented. The application of the logic of fuzzy sets in expert systems of environmental monitoring is considered in the work of Slesarev M.U. and Makarova G.V. [5]. At the same time, these authors believe that the schemes of classical logic are insufficient for analyzing the complex problems of ecologically oriented urban planning. Being disagree with this setting, the authors of the article are guided by the works, in that use the tools of classical formal logic as a mean of synthesis and analysis of electrical circuits. In the second part of the article the authors turn to the discussing questions of the discovery for the use. The potential of the laws and rules of classical formal logic is far from exhausted, according to the authors. That is confirmed by the historiography of the problem under consideration in this section. The main points of the return to logical developments after a long period of persecution this sphere of knowledge in the USSR were considered by such authors as Kuzicheva Z.A. [6], Verstin I.S. [7], Biryukov B.V. (for the last of the logicians, see: [8]). The authors of the article also rely on the conclusions proposed not only in joint works, but also in the theses of Biryukov B.V. and Kuzicheva Z.A. [9], as well as in the study of Biryukov B.V. and Shakhov V.I. [10].

Russian historians of logic and mathematics are arguing about the priority in developing the logic of relay contact circuits, i.e. one of the first technical applications of logic, the interpretation of mathematical logic and Boolean algebra on relay contact circuits. The authors can mention the study of Bazhanov V.A. [11], Levin V.I. [12] and a number of others, among the latest works. Various estimates of Shestakov's activity are given in the works listed above. The authors intend further to address to some of these estimates. It should be noted the biography of S.A. Yanovskaya, the creator of the Russian school of mathematical logic. The biography has been published in recent years as a part of the series published at the initiative of Professor Biryukov B.V., who himself was a disciple and follower of ideas of S.A. Yanovskaya. In a number of works, it is noted that S.A. Yanovskaya was the first one who assessed Shestakov's contribution to logical and mathematical knowledge. She repeatedly emphasized his priority in the field of technical applications of the science, and also held seminars on his "logic of relay contact circuits" [13]. The appeal of outstanding logicians and modern engineers to the topic of the first technical applications of logic serves as an additional confirmation of the relevance of this problem.

Depending on the approaches that the authors of the paper apply to in some of its paragraphs, it will be appropriate to refer to the scientific heritage of the engineer and mathematician chosen by us.
In particular, the authors take into account the conclusions containing in the works of Shestakov V.I. and his western colleagues [14-16].

2. Methods

The subject area of the investigation determined the methods used. First of all, the method of constructing formulas for the logic of propositional calculus is used. Correctness, i.e. the identical truthfulness of the reasoning schemes that justify the stability of structures is determined by a tabular method or by formal logical transformations according to the rules of systems of natural inference. The last of the methods is presented in the paper. In this case, the elementary statements participating in the reasoning are replaced by variables. The authors use the following alphabet of the propositional calculus logic language:

1. Logical terms:
   - \( \neg \) – sign of negation,
   - \( \land \) – sign of conjunction,
   - \( \rightarrow \) – sign of implication,
   - \( \lor \) – sign of the disjunction

2. \( p, q, r, p_1 \), etc. are propositional variables that replace (e.g. serving as symbols) elementary statements or, more precisely, narrative sentences expressing the given statements (e.g., "It's raining", "Earth is the planet of Solar system", etc.). Propositional variables being elementary formulas are part of simple and complex variables.

3. (,) – the left and right brackets;

In addition, the definition of a "correctly constructed propositional formula" is introduced, as a generalization of the concept of a variable: 1. Propositional variables are formulas of the logic language of the propositional calculus, i.e., they are correctly constructed propositional formulas. 2. If \( N \) and \( \exists \) are formulas of the logic language of the propositional calculus, then \( (N \land \exists), (N \rightarrow \exists), (N \lor \exists), \bar{N}, \bar{\exists} \) is also the essence of the formula. In this case, they say that the variables \( N \) and \( \exists \) act as meta-variables, intended to substitute for specific propositional formulas (comp. with [17]).

When converting the formulas of the language of propositional calculus logic, the authors use the following formal-logical laws: the rule of distributivity of a conjunction relatively to disjunction, the commutative law of disjunction, the disjunction association rule, the rule of representing implication in the form of disjunction, the discard rule, and several others.

Our work is devoted to the history of applied applications of logic. That is why, when referring to the history of mathematical logic, to the stages of the formation of Russian schools of mathematical logic in the XX-th century, to the individual pages of the history of creation of logic of relay-contact schemes of the degenerated (A-class), the authors use the biographical method, the method of retrospective analysis of source and the comparative-historical method.

3. Results

As a possible interpretation of the conclusions of propositional logic, the model of relay circuits consisting of switches connected by conductors has become more famous. These circuits relate to one of the types of electrical circuits considered in the theory of electrical circuits and machines. Just they are used as a model of algebra of logic, developed in the XIX century by G. Boole. The priority in the application of electrical circuits for the interpretation of the laws of Boolean algebra belongs to the domestic logician V.I. Shestakov, his American colleague C. Shannon and the Japanese mathematician and engineer A. Nakashima. The researchers came to the idea of using relay circuits independently of each other, but the American logician published the results of his research, as historians believe, much earlier than the other two engineers.

Now we showed answer the question: how do relay contact circuits modeled according to the laws of mathematical logic work? Contacts that are used in the schemes considered by Shestakov and
Shannon can be breaking and closing, which corresponds to negative and affirmative propositions in the language of propositional logic. The closing contact in the non-operating state breaks the circuit, in the operating one – it closes the circuit. The action of the breaking contact will be exactly the opposite.

We conditionally assume that the switch-contact can be in two states, – conductivity and non-conductivity. The conductivity–non-conductivity state is an analogue of the true-false value of variables in the logic of the propositional calculus. In Boolean algebra and in the logic of propositional calculus, the formula takes on the value of false or true. In accordance with the false, a contact is triggered, resulting from an external action on a switch-relay in which the electrical circuit is broken. On the contrary, the true is such a state of the circuit, when it is closed when the current is supplied and contacts are triggered. Using the contact diagram and relay as a model, you can set the basic operations that are provided in propositional logic. Conjunctions, disjunctions and negations appear in this way. Disjunction is understood as parallel, and conjunction is as a serial connection of contacts or complexes of contacts united by conductors. The operation of negation concerns only some contacts and is the breaking of the closing contact, the value of true corresponds to which. In other words, the closing contacts are interpreted as propositional variables. The breaking contacts are the negation of propositional variables in this interpretation. Diagrams of switch contacts can be written as the formulas. Conversely, the formulas of the propositional theory can be written as the schemes of switch contacts. In order to show how modus ponens can be represented by means of relay circuits, i.e. the affirmative mode of conditional-categorical inference, it is necessary to present the implications of its formula in the form of disjunctions. Then:

\[
\begin{align*}
\big( (p \to q) \land p \big) & \to q & (1) \\
\big( \neg p \to q \land p \big) & \to q & (2) \\
\big( (p \lor q) \land p \big) & \lor q & (3) \\
\big( \neg p \lor q \land p \big) & \lor q & (4) \\
\big( (p \land \neg q) \lor \neg p \big) & \lor q & (5)
\end{align*}
\]

Let us explain the above transformations:
Formula (2) follows from (1) according to the rule of representation of implication in the form of a disjunction
Formula (3) - from (2) according to the rule of representation of implication in the form of a disjunction
Formula (4) - from (3) according to De Morgan’s rule
Formula (5) - from (4) according to De Morgan’s rule

The statement \( \big( \neg p \lor q \land p \big) \lor q \) should be regarded as equivalent to the formula of the conditionally categorical syllogism of modus ponens. Its scheme (figure 1) will look like this:

**Figure 1.** Relay contact scheme corresponding to the formula of the conditionally categorical syllogism modus ponens
If there is a current in the circuit, this scheme will work. Parallel connection of the opening and closing contacts makes it work.

The authors of the article see an example of the application of system approach in applied technical disciplines in the application of formal and modern mathematical logic in the analysis and synthesis of relay contact circuits. This application made it possible to pay attention to the principal characteristics of systems. We note here that the system approach is based not only on the category of a system, but also on the category of an element associated with it, since the use of systems is impossible without knowing their elements [18]. Such elements of A-class systems are contacts and switches, to which are put in accordance propositional variables, and the logical constants – conjunction and disjunction – are put in the way of connecting switch contacts. At the same time, in electric systems consisting of contacts and relays, in the elimination of system elements is provided, bringing the entire system to a simpler form.

The above circuit can be optimized, only the closing contact is left in the transformation of formula (1). Applying the rules for discarding a disjunction, the distributivity of a conjunction relatively to disjunction, the associative law of the disjunction, we get:

\[
\begin{align*}
(p \land \overline{q}) \lor \overline{p} & \lor q \\
(p \lor \overline{p}) \land (q \lor \overline{p}) & \lor q \\
\overline{q} \lor \overline{p} & \lor q \\
\overline{p} \lor \overline{q} & \lor q \\
\overline{p} \lor (\overline{q} \lor q) & \\
\overline{p} &
\end{align*}
\]

Formula (6) is obtained from formula (5) by the rule of the distributivity of a conjunction relatively to disjunction.

Formula (7) - from (6) in accordance with the Second discard rule.

Formula (8) - from (7) according to the commutative law of disjunction.

Formula (9) - from (8) by the rule of associative of a disjunction.

The formula (10) - from (9) according to the Second discard rule.

4. Discussion

The subject of discussions on this topic is closely related to the history of the development of relay contact circuits logic. Researchers are still arguing who actually creates this logic. The situation in the history of science is not exceptional.

Let us recall only some examples. The law of the difference of functions of the anterior and posterior roots of the spinal cord is one of the important laws of psychophysiology called the Bell-Magendie law. Although the first author is the author of only a brief memoir in which the hypothesis was spoken on. It was experimentally confirmed later by the numerous experiments of François Magendie (1783-1855) [19, p.187-188]. Let us also recall Leibniz's dispute with Newton for the priority in the discovery of the differential calculus and the biased attitude toward the dispute of logicians and mathematicians. We may remember how Newton fought with the memory of his predecessor Robert Hooke, in every way hushing up his merits to classical mechanics? In this respect, it is quite appropriate to compare the listed cases with the facts in Russian science of the XX-th century. Indeed, the logical search of V.I. Shestakov was not met with response from domestic physicists and electrical engineers. It was not easy, as historians of science emphasize, Shestakov's relations were with the representatives of the school of M.A. Gavrilov. The relations were developed in the post-war period in the USSR approximately the same range of problems as V.I. Shestakov.
The lack of support from the Russian scientific community, as the authors of this paper are convinced, is not the only reason the priority in developing the logical theory of relay contact circuits belongs to American researcher. The fact is that Nakashima and Shestakov worked under conditions of rigid autocratic regimes that put the scientific research under state control. The communication with representatives of Western science was minimized. Just this isolation was the reason that neither Shestakov nor Nakashima were recognized as pioneers of the new method, as V.I. Levin suggested. But this explanation cannot be considered quite satisfactory either. Many thinkers of the past from Zenon of Elea, the subject of the tyrant Nearche (see [20]), up to Werner Heisenberg, a contemporary of the dictator Hitler, worked under the conditions of a rigid authoritarian dictatorship. But these facts did not cause the refusal to recognize their scientific merits and discoveries. Francis Bacon's consciousness was undoubtedly influenced by the state ideology of absolutist England, and he himself was a corrupt representative of the bureaucratic apparatus. The Viscount of Verulam, being unfree as an official, was free as a philosopher and natural scientist. It is necessary to separate Bacon the bribe-taker from the Bacon-researcher. And the work "for Hitler" did not prevent the recognition of Werner Heisenberg's contribution to the creation of a quantum-field picture of the world. The ideology plays a significant, but not decisive, role in the dynamics of the exact sciences. It was not decisive for the hero of the article, too.

Finally, it is worth taking into account own view of V.I. Shestakov, who spoke about the simultaneity of the discovery of the logical theory of relay-contact circuits by all three researchers. Sophia Aleksandrovna Yanovskaya assessed quite highly the contribution of V.I. Shestakov in solving the problem of using logic in technical sciences. The native mathematician wrote about his priority in the article of 1947, which was published in the digest "Mathematics in the USSR for thirty years (1917-1937)" [21]. Then in 1948 she repeated this idea in an afterword to the Russian translation of A. Tarski's book [22]. Details of these two publications of the famous domestic mathematician S.A. Yanovskaya are written in the article by B.V. Biryukov, O.A. Borisova, and V.I. Levin [23]. Here we will not repeat the theses of this study. We only note that the lack of attention to V.I.'s ideas is accompanied the scientist throughout his life. While being a postgraduate student, Shestakov received a negative response from Professor Gabriel Semenovich Gorelik (1906-1957), in whose laboratory he worked at the Physics Faculty of the 1-st Moscow State University (there were two state universities in Moscow at that time). The esteemed professor considered that "postgraduate student Shestakov unsatisfactorily fulfilled the plan of his scientific work". The study of a young scientist in the field of applying algebra of logic to relay circuits by the opinion of the scientific master "did not guarantee his defense of Ph.D. thesis" (cited in [23]). The opinion of a prominent scientist and specialist in radio physics, acoustics and optics could not but have consequences for Shestakov, and negative ones. And here again we should pay attention to how different were the ways to the discoveries of American and Japanese engineers. If Claude Shannon's researches were supported by the American state and American business and if the Japanese engineer, working independently, as V.I. Levin wrote, relied on the help of colleagues and friends, then Shestakov was alone in his search and had to reckon with the negative attitude of famous Soviet physicists to his innovative calculations. It is regrettable that Shestakov's name was held back not only by foreign, but also by domestic authors. So, in the article about the theory of relay-contact circuits, placed in the "Encyclopedia of Cybernetics", we read: "The theory of relay-contact circuits began to develop from the 30's. (USSR, Japan, USA) ... In general, the problem of the theory of relay-contact circuits was formulated in 1945-50 in the works of the Soviet scientist M.A. Gavrilov "[24]. Shestakov's name was never found here.

5. Conclusion
Based on the analysis of the results of the study, the debate on priorities in the discovery of the technical application of formal logic, which was the subject of the discussion part of the paper, summarizing the facts described in the previous sections, the author comes to the conclusion that it is possible to use a priori theoretical constructs of mathematical logic in analyzing and synthesizing support systems of a modern town as a whole: from transport to energy systems. An appeal to the
logic of Shestakov’s relay-contact circuits is one of the examples of such use, capable of making the search of town planners and electrical engineers more focused. The study of contentious issues of the history of science and technology can bring benefits, as well as the definition of priorities in certain logical discoveries. This was done in the discussion part of the study. The analysis of the achievements of the previous stage of development of science and technology will help determine the vector of further development.

The experience of constructing the logic of relay-contact circuits by Shestakov is extremely important today. The logic was effectively used in various areas of technical modeling and in justifying the sustainability of buildings and constructions. Obviously, as a result of using mathematical logic, application areas will only benefit. On the other hand, Shestakov’s experience allows us to understand how the empirical spheres of human knowledge and activity can help theoretical knowledge, indicate the ways of further development of logical and mathematical teachings.

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