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THE TECTOLOGY OF DYNAMIC SYSTEMS AND THE PHENOMENON OF HYPERVALENCE INTERACTION IN THE STRUCTURAL EQUATIONS OF THE GENERALIZED ELECTRIC CIRCUIT

The paper presents a number of the solutions of the important and interrelated theoretical problems, having technology-specific and general natural significance. Taken together and in the interaction with one another, they lay the theoretical basis for the formation and development of the new trend in classical electrical engineering, characteristic feature of this trend is the construction of the generalized, regarding the number of the degrees of freedom, continuous in time, homogeneous or mixed by their nature dynamic systems, as of purely electrical and combined physical origin, their structural analysis and formalization on the deductive basis of the process of mathematical and physical identification.

In the connection of the above-mentioned the author determined and revealed the essence of the unknown general natural phenomenon of the hyperforce (hypervalence) interaction between the elementary structural links which is observed or can be observed in the dynamic systems with the concentrated parameters of the random physical nature and complexity in the process of their motion in the phase space under the impact of the internal and external forces. It is shown and mathematically proved that in general case the internal force interaction between the structural elements of the dynamic system is at the same time multidimensional and corresponds to the dimensionalities of the subspaces of the system topological space, which are determined by all the combinatorial combinations from the number n to the number k, where the number k belongs to the area $2 \le k \le n$, and n is the number of the degrees freedom of this system. In such embedded subspaces the available multidimensional forces of the random dimensionality are independent one from another. Among others, this simplifies the predominant, for grater part of theories and scientific systems, paradigm concerning the possibility of exceptionally binary ($k = 2$) presentation of the character of the force interaction (and correspondingly mathematical relations) between the structural elements of the dynamic systems during their motion.

Accounting the phenomenon of the hyperforce (hypervalence) interaction considerably broadens the classes of the studied dynamic systems.

On the example of the electric engineering systems the application of Lagrange-Maxwell equations enabled to solve the number of decomposition problems, which form the basis of one of the fundamental problems of the theoretical electrical engineering – construction of the electric circuit. generalized by the number of the degrees of freedom .

The obtained results, namely topological structural diagram of the generalized electrical circuit and structurally determined system of differential equations of its motion (structural equations), today have the highest degree of generalization and deductively embrace wide classes of the electrical circuits and systems – both already known and possible ones.

Keywords: *physical phenomenon of hypervalence interaction, multidimensional force (hyper-force), generalized electrical circuit, dynamic system, Lagrange – Maxwell equations, structural equations of electrical circuit, the first and the second systems of generalized coordinates.*

Introduction

One of the problems of theoretical electrical engineering is construction of *electrical circuits with lumped parameters, generalized by the number of degrees of freedom.*

Successful solution of the set problem reveals new qualities in the classical (Kirchhoff) electrical engineering and lays the basis for formation and development of the new trend in it – structurally analytical generalized theory of electrical engineering. Its essential feature is the ability to formalize, on a deductive basis, the process of mathematical and physical identification of physical and engineering dynamic systems of both purely electrical (electromagnetic) and combined physical origin, which are continuous in time, homogeneous or mixed by their nature.

At the level of problem statement, the essence of the generalized electrical circuit concept is disclosed in an explicit or indirect form in many research works of the following authors: J. Cl. Maxwell [1], A. Poincare [2], G. Kron [3], H. Hepp [4], A. Ango [5], A. K. Shidlovskiy and Miliakh [6], A. I. Veinik [7], K. Shimoni [8], V. A. Venikov [9], N. N. Garnovskiy [10], G. Y. Pukhov [11], V. S. Perkhach [12] and many others.

At the same time, from the above works it is evident that in spite of the importance and relevancy of the stated problem, it has not been solved yet even at its root and remains conceptually unsolved.

However, in recent works [13, 14] important results were obtained which laid the necessary theoretical basis for its solution.

Thus, the *aim of the present work* is to develop a conception of the generalized electrical circuit with the highest degree of generalization (compared to that achieved to date), based on the natural phenomenon of hyperforce (hypervalence) interaction, revealed by the author, and to build its structural scheme. Besides, the work aims at the formation of structurally defined differential equations of motion – *structural equations* of the generalized circuit.

1. General considerations

Construction of generalized abstract systems (superstructures) with the highest logical force (generalization degree) is one of the most important factors in the development of science.

At the same time, at different historical stages the need for such theoretical superstructures was not always of externally conditioned nature and had varying degree of expression. Depending on the current state and needs of the society, its demands quite often had inertial character in a certain form compared to the possibilities for the development of some theories and scientific systems that obeyed the internal logic. This resulted, at least, in incomprehension of the practical expediency of the obtained scientific results and in extreme cases – in their categorical rejection, until systematic and radical changes started to occur in the socioeconomic formation itself.

Numerous facts from the history of science are a strong evidence for that. In this respect, we can recollect a rather complicated, even tragic, history of establishing the *heliocentric* instead of geocentric system in the process of forming a general picture of the Universe.

The revival of a socioeconomic formation always began from a deep aversion to obsolete reactionary forms and to their content. Therefore, in the context of the necessity for further development the society also stimulated the development of science by setting important problems. Although they usually were of applied character, their solution was impossible without a theoretical provision, based on generalized abstract system superstructures, which led to their numerous practical applications and, therefore, to their recognition as well.

Theoretical basis of *the classical electrical engineering* (including theoretical fundamentals of electrical engineering) as an interdisciplinary science (among fundamental sciences) developed *under similar conditions*: from accumulation of separate experimental facts, phenomena and laws to their generalization with subsequent practical application of the obtained theoretical superstructures. Therefore, its powerful analytical potential enables solving a wide range of both applied and theoretical problems that currently arise in the process of socio-material production, particularly, in the electrical engineering segment of national and supranational economies.

However, in accordance with *the law of historical development of socioeconomic formations*, qualitatively new problems (and under new conditions) arise before the societies of both separate developed countries and their associations.

In the narrow sense, the essence of the above-mentioned is clearly set out in the main statements of the conception of the *third industrial revolution* [15]. Its paradigm is integration of the modern informational internet technologies with *updated electrical power systems* built on qualitatively new principles, where dominant is *the idea of abandoning the traditional extractive carbon energetics* with its too hierarchal infrastructure and adoption of energetics with maximally decentralized network. This network includes a large number of low-power renewable energy sources and consumers, maximally close to them, the structure of which is organized so that excessive electrical energy could be returned to the network or received from the same network, if necessary [15].

In addition to the above, it should be mentioned that in May of 2007 the European Parliament issued official declaration, where the conception of the third industrial revolution was presented as a *long-term economic vision and the roadmap for the European Union*. Such world-known companies as Philips, Schneider Electric, IBM, Cisco Systems, Acciona, CH2M Hill, Arup, Adrian Smith + Gordon Gill Architecture, Q-Cells are actively involved in this process and create the necessary infrastructure.

In the broad sense (historical aspect), the above leaves no doubt (at least as far as the author of this article is concerned) in the emergence of a new society. Its historical mission is *to change the socio-economic formation,* when creation of a new formation leaves no chances for further hegemony of the old one.

It should be noted that for a long time the world community witnessed not only progressive changes and unique qualities brought by the socioeconomic formation, based on the *carbon energetics*, but was also a victim of deep and horrible contradictions, conflicts, crises and wars, which it provoked and which were aggravated with the reduction of the resource base.

The price which the humanity had to pay for its natural right to use energy resources of the planet was too high to further ignore *alternative energetics*, particularly, *heliocentric energetics*.

It is clear enough that *without reforming and radical restructuring* of the socio-material production of each separate country and of all of them simultaneously – of their production forces and relations – no qualitative and progressive changes in the world economy will be principally possible.

It should be added that the above-mentioned equally concerns the countries which for certain reasons are still at starting positions (let us call it this way) or will have to reach such positions, as any of the societies in this countries will have no desire to wait for a long time.

As for Ukraine, no doubt that it will eventually find its way as well. Unlike failures, no victory can be achieved without a fight.

2. Alternative structural scheme of the generalized electrical circuit

Thus, *in order to satisfy the needs of the alternative electrical power engineering in the future, the basis of the theoretical electrical engineering should be qualitatively reformed today and brought into conformity with the necessity to solve not only current problems but also to address future challenges*.

Primarily, this concerns the theory *of electrical and magnetic circuits* as it is the most significant component of it and is precisely the theory capable of adequately representing energy processes in electric power systems under various modes of their operation.

Taking the above into account, creation of the conception of the generalized electrical circuit is a relevant problem that is of primary importance at the current stage of electrical engineering development.

One of the most significant basic elements in the theory of the generalized electrical circuit is its structural scheme, which simultaneously represents composition (i. e. the set of structural elements and their properties), topology (i.e. relations between said structural elements as a set of their subsets, first of all in physical and mathematical sense) and tectology [16] – general organizational basis of the structure of this generalized abstract system.

A generalized electrical circuit with this structure is developed and presented in [14] (Fig. 1). An

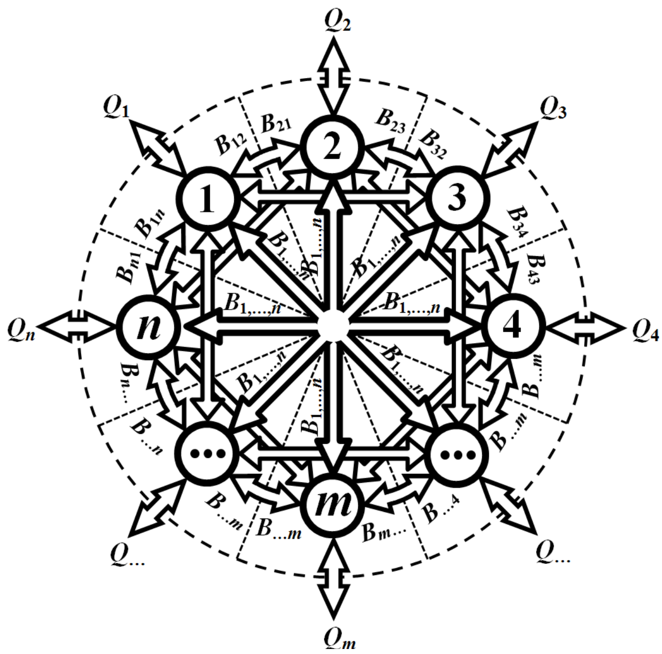

Fig. 1. Structural scheme of the dynamic system of an arbitrary nature, taking into account the phenomenon of hyperforce (hypervalence) interaction

essential property of the generalized electrical circuit, presented in Fig.1, is *the highest degree* of generalization (logical force) among those known for today. Its significant sign is availability of *full topology* in physical and mathematical relations between its structural elements – standard elementary links, which is a phenomenological manifestation of the general natural phenomenon (physical one in this case) of hyperforce (hypervalence) interaction.

Thus, the proposed generalized abstract system encompasses the totality of the known and possible (and even imaginary) electrical circuits, taken separately, and subordinates their generalized abstract classes with different and, certainly, lower generalization degrees.

It is worth reminding that electrical circuits are dynamic systems of mostly artificial origin. At the same time, processes and phenomena observed in them are of general natural character and obey general laws of nature, primarily, the laws of physics and mathematics. Therefore, in the development of conception of the generalized electrical circuit it is important to remember the following significant and repeatedly proved rule. If in the processes and phenomena, having an extremely diverse nature of physical reality, generalized abstract superstructures ignore direct or indirect influence of the known or unknown, yet essential, factors and relations, *such superstructures will eventually turn out to be not adequate and will require replacement for hypothetically deductive theoretical systems, more corresponding to the new realities.* The latter, in their turn, will be recognized as systems with a higher generalization degree (logical force) only in the event if they do not contradict the local truth of the prevailing (until recently) generalized concepts and, because of their higher deductive capacity, will subordinate them in a natural way.

Though at first glance it seems to be a contradiction, the history of science repeatedly confirmed the truth of this rule by convincing facts. Therefore, it regards the above rule as *a reliable way of the scientific truth formation, which is revolutionary in form but evolutionary in meaning.* It should be noted that, although both of the above qualities are necessary, none of them alone could be sufficient: neither evolution without form, nor revolution without meaning.

Thus, in the context of the aforementioned the *abstract system of the generalized electrical circuit*, shown in Fig. 1, do not deny the general rule but is the evidence of it.

The most successful attempt to solve this problem was proposed in [13], where the author analytically built and presented *structural equations* of the generalized electrical circuit, which, again, made it possible to form generalized structural schemes and electrical circuits with *an extremely high generalization degree* and deductive coverage of the wide classes of electrical circuits – both known and possible. At that time, it proved a strong logic force of the proposed system superstructure.

However, solution of the problem of building a generalized electrical circuit presented in [13], eventually, turned out to be only partial with inherent *insufficient deductive capacity*, which was disclosed in [14].

Main disadvantage of the proposed structure of the generalized electrical circuit was a false idea that, unfortunately, still prevails in the majority of theories and scientific systems. It consists in *an exclusively binary (!) representation of the character of mathematical relations in a structure among the elements of the generalized abstract system.*

A representative example of such an approach is *the theory of graphs* with its universal application area, where the basic notion of *graph* is derived from the condition of *parity* of vertexes, convergent (incident) to any edge. As the edge is abstract representation of interaction (interconnection) between the vertexes, then according to the current ideas of the theory, such interaction is to occur *only between two* (!) vertexes.

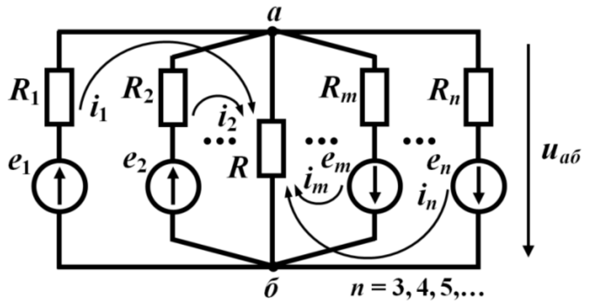

Fig. 2. Manifestation of the phenomenon of hyperforce (hypervalence) interaction by the example of separate classes of electrical circuits

Therefore, exclusively binary character of the physical and mathematical relations in the structure of the generalized electrical circuit substantially weakens its logical force and so a considerably *bigger part* of electric circuits and electric engineering systems is ignored, even those well-known and demanded in practice (Fig. 2).

At the same time, in this work [14] it is proved that the above disadvantage is *critical* and, according to the essence of the generally natural hyperforce (hypervalence) interaction phenomenon, it is principally impossible to overcome this disadvantage without radical revision of the principle of establishing physical and mathematical relations between structural elements of the generalized system.

3. Phenomenon of hyperforce (hypervalence) interaction and the principle of the system hyper-connectivity

The concept of *force* as a measure of interaction deeply penetrates the foundation of all science and has an extremely high methodological importance. Most of the phenomena and processes, identified and described by natural, engineering and socio-economic sciences, are inherently connected with this concept.

As it is known, *internal forces of interaction* in a dynamic system are the forces of interaction between its structural components. In our case, such components of the system are the smallest and structurally indivisible *standard elementary links*, each of them being capable to interact with others and create not only pairwise but also *hyperforce (hypervalence*) *bonds*, as it is shown in Fig. 1.

In particular, Fig.1 represents all internal forces which because of hyperforce (hypervalence) interaction between all of its standard elementary links appear or may appear in a dynamic system during its motion. In a general case, these forces have *different order of dimensionality k*.

The phenomenon of hyperforce (hypervalence) interaction is a general natural phenomenon observed in physical and engineering dynamic systems of different nature, manifestation of which reflects the ability of standard elementary links to interact (or to establish interconnections) by *multidimensional* internal generalized interaction forces, independent of one another but dependent on generalized coordinates and (or) on the velocities of the system links, *in various combinatorial sets with n according to k,* provided that k belongs to the region

$$2 \le k \le n$$

and n is a *number of the system degrees of freedom*.

Therefore, by *multidimensional internal forces of interaction* (or *hyperforces*) in a dymamic system we will mean all k-dimensional internal forces or resultant forces, provided that $2 \le k \le n$.

For the generalized electrical circuit built taking into account the phenomenon of hypervalence interaction, as it is shown in Fig. 1, total number of the equivalent internal interaction forces that can act simultaneously between all standard elementary links will be given by

$$N(n)=\sum_{k=2}^{n}C_n^k=\sum_{k=2}^{n}\frac{n!}{k!\,(n-k)!}=2^n-n-1\,, \tag{1}$$

while for the generalized electrical circuit, presented in [13], where only two-dimensional (or pairwise) internal interaction forces *k = 2* are taken into account, such a quantity is essentially smaller and is equal only to one of the group of the components in formula (1), namely

$$C_n^2=\frac{n!}{2!(n-2)!}\,. \tag{2}$$

For complex systems of electrical circuits with multiple degrees of freedom, the value of binominal coefficient (2) is an incomparably small part of sum (1) of such coefficients:

$$\frac{C_n^2}{\sum_{k=2}^{n}C_n^k}\cdot 100\%=\frac{100\%}{1+\sum_{k=3}^{n}\frac{C_n^k}{C_n^2}}=\frac{100\%}{1+\sum_{k=3}^{n}\frac{2!(n-2)!}{k!(n-k)!}}\,, \tag{3}$$

as the value of the sum in formula (3) *increases significantly* with the growth of *n*. E.g., if $n=15$, the above-mentioned part is only 0.321% while if $n=10$, it is 4.44%, and when $n=5$, it is 38.46%. This proves the relevance of the generalized electrical circuit, built in [13], only *for small values of n*, i.e. for *simple dynamic systems with small value of the number of degrees of freedom*.

Generalization of electrical circuit requires *the highest connectivity degree* of each from its *n* standard elementary links in the system. Therefore, hyperforce interaction of any separate standard elementary link with other links of the system must encompass all the *possible combinations:*

$$S_n^k=C_{n-1}^{k-1}=\frac{(n-1)!}{(k-n)!\,(n-k)!}\,, \tag{4}$$

and, namely, the set $\left\{S_n^2=C_{n-1}^1;\ldots;S_n^m=C_{n-1}^{m-1};\ldots;S_n^n=C_{n-1}^{n-1}\right\}$, where each of the numbers S_n^k in (4) is the number of combinations with *n* according to *k* of the said standard elementary link with other links of the system.

The above condition, which is a significant sign of the generalized electrical circuit as a dynamic system, we will define as *hyper-connectivity principle* of standard elementary links.

It should be noted that for dynamic systems proposed in [13], i. e. for systems of *pairwise interaction*, all the combinatorial possibilities of any separate link are limited only to *k = 2* and their possible number does not exceed the value

$$S_n^2=C_{n-1}^1=n-1.$$

4. Standard elementary links and the principle of standard elementary links

Standard elementary link of a dynamic system with lumped parameters is its smallest and structurally indivisible part, energy state of which depends only on a single (its own) generalized coordinate and generalized velocity (generalized pulse) on the condition of the absence of force interaction with other such links and, if such interaction exists, also on generalized coordinates and velocities of corresponding adjacent interacting links [13, 14].

The change of energy state of a standard elementary link occurs because of its motion under the action of external and internal *multidimensional forces.* Motion of a standard elementary link is the time change of its state in relation to the state of other standard elementary links or of the given system of generalized coordinates.

Therefore, the state of a standard elementary link is determined by current values of its generalized coordinate and generalized velocity (or generalized pulse) relative to the coordinate system chosen as an actual one.

For electrical circuits in *the first system* of generalized coordinates *independent closed loops* serve as standard elementary links, *charges of the loops* serve as generalized loops, *currents of the loops* are generalized velocities, *magnetic flux linkages* are generalized pulses, *electrical voltages* serve as generalized forces and as *electromotive forces* of the energy sources in the case of external action.

In *the second system* of generalized coordinates *independent node pairs* are standard elementary links, *voltages* between the nodes of said pairs are generalized velocities, their *integrals* (or *magnetic flux linkages*) determine generalized coordinates and *electrical charges* serve as generalized pulses, *electric currents* and *currents of the current sources* serve as generalized forces.

The principle of standard elementary links consists in the following: each of the said dynamic systems, irrespective of their physical nature, could be represented in the unified form, i.e. divided into interacting standard elementary links.

As each of such links is bijectively (mutually uniquely) interrelated with its own generalized coordinate and generalized velocity (or pulse), their number is strictly regulated and corresponds to the number of the generalized coordinates and to the number n of the system degrees of freedom.

5. Structural equations of the generalized electrical circuit in the first system of generalized coordinates, taking into account the phenomenon of hyperforce (hypervalence) interaction

For building equations we will use *Maxwell – Lagrange equations*, which correlate motion of the generalized electrical circuit and arbitrary number n of the degrees of freedom.

1) In the first system of generalized coordinates Lagrange – Maxwell equations have the form of

$$\frac{d}{dt}\frac{\partial W_м}{\partial i_m}+\frac{\partial W_e}{\partial q_m}+\frac{\partial \Phi_e}{\partial i_m}=e_m,\quad m=1,2,\ldots,n, \tag{5}$$

where $W_м$, W_e, Φ_e – energy functions of the generalized electrical forces.

2) *General energy $W_м$ of magnetic field* of the electric circuit is determined as total energy of all magnetic fields of inductive elements that compose this field [17].

Thus, taking into account the phenomenon of hyperforce (hypervalence) interaction, for energy function $W_м$ we have [14]:

$$\begin{aligned}W_м=&\frac{1}{2}\sum_{s_1=1}^{n}L_{s_1}i_{s_1}^2+\frac{1}{2}\sum_{s_1=1}^{n-1}\sum_{s_2=s_1+1}^{n}L_{s_1,s_2}\left(i_{s_1}\pm i_{s_2}\right)^2+\frac{1}{2}\sum_{s_1=1}^{n-2}\sum_{s_2=s_1+1}^{n-1}\sum_{s_3=s_2+1}^{n}L_{s_1,s_2,s_3}\left(i_{s_1}\pm i_{s_2}\pm i_{s_3}\right)^2+\\&+\cdots+\frac{1}{2}\sum_{s_1=1}^{1}\sum_{s_2=s_1+1}^{2}\cdots\sum_{s_n=s_{n-1}+1}^{n}L_{s_1,s_2,\ldots,s_n}\left(i_{s_1}\pm i_{s_2}\pm\cdots\pm i_{s_n}\right)^2,\end{aligned} \tag{6}$$

where each $L_{s_1,\ldots,s_\nu}$, $(2\le\nu\le n)$ – ν-loop mutual inductance and L_{s_1} – self-inductance.

Based on (6), after corresponding mathematical transformations, for m-th arbitrary loop with $1\le m\le n$ we can finally write:

$$\begin{aligned}\frac{d}{dt}\frac{\partial W_м}{\partial i_m}=&L_m\frac{di_m}{dt}+\sum_{\substack{s_1=1\\s_1\ne m}}^{n}L_{m,s_1}\frac{d}{dt}\left(i_m\pm i_{s_1}\right)+\sum_{\substack{s_1=1\\s_1\ne m}}^{n-1}\sum_{\substack{s_2=s_1+1\\s_2\ne m}}^{n}L_{m,s_1,s_2}\frac{d}{dt}\left(i_m\pm i_{s_1}\pm i_{s_2}\right)+\\&+\sum_{\substack{s_1=1\\s_1\ne m}}^{n-2}\sum_{\substack{s_2=s_1+1\\s_2\ne m}}^{n-1}\sum_{\substack{s_3=s_2+1\\s_3\ne m}}^{n}L_{m,s_1,s_2,s_3}\frac{d}{dt}\left(i_m\pm i_{s_1}\pm i_{s_2}\pm i_{s_3}\right)+\cdots+\\&+\sum_{\substack{s_1=1\\s_1\ne m}}^{2}\sum_{\substack{s_2=s_1+1\\s_2\ne m}}^{3}\cdots\sum_{\substack{s_{n-1}=s_{n-2}+1\\s_{n-1}\ne m}}^{n}L_{m,s_1,s_2,\ldots,s_{n-1}}\frac{d}{dt}\left(i_m\pm i_{s_1}\pm i_{s_2}\pm\cdots\pm i_{s_{n-1}}\right).\end{aligned} \tag{7}$$

3) The structure of energy function W_e we will study in a similar way.

Taking into account the phenomenon of hyperforce (hypervalence) interaction, general energy W_e *of the electrical field* of the generalized electrical circuit is equal to the sum of energies of all electrical fields, created in the inductive elements that compose the generalized circuit [14, 17]:

$$W_e = \frac{1}{2}\sum_{s_1=1}^{n}\frac{q_{s_1}^2}{C_{s_1}} + \frac{1}{2}\sum_{s_1=1}^{n-1}\sum_{s_2=s_1+1}^{n}\frac{\left(q_{s_1} \pm q_{s_2}\right)^2}{C_{s_1,s_2}} + \frac{1}{2}\sum_{s_1=1}^{n-2}\sum_{s_2=s_1+1}^{n-1}\sum_{s_3=s_2+1}^{n}\frac{\left(q_{s_1} \pm q_{s_2} \pm q_{s_3}\right)^2}{C_{s_1,s_2,s_3}} + \cdots + \frac{1}{2}\sum_{s_1=1}^{1}\sum_{s_2=s_1+1}^{2}\cdots\sum_{s_n=s_{n-1}+1}^{n}\frac{\left(q_{s_1} \pm q_{s_2} \pm \cdots \pm q_{s_n}\right)^2}{C_{s_1,s_2,\ldots,s_n}}, \quad (8)$$

where each $C_{s_1,\ldots,s_\nu}$, $\left(2 \le \nu \le n\right)$ – ν-loop mutual capacitance and C_{s_1} – self- capacitance.

Then, based on (8), for m-th independent loop we have

$$\frac{\partial W_e}{\partial q_m} = \frac{q_m}{C_m} + \sum_{\substack{s_1=1\\ s_1\ne m}}^{n}\frac{q_m \pm q_{s_1}}{C_{m,s_1}} + \sum_{\substack{s_1=1\\ s_1\ne m}}^{n-1}\sum_{\substack{s_2=s_1+1\\ s_2\ne m}}^{n}\frac{q_m \pm q_{s_1} \pm q_{s_2}}{C_{m,s_1,s_2}} + \sum_{\substack{s_1=1\\ s_1\ne m}}^{n-2}\sum_{\substack{s_2=s_1+1\\ s_2\ne m}}^{n-1}\sum_{\substack{s_3=s_2+1\\ s_3\ne m}}^{n}\frac{q_m \pm q_{s_1} \pm q_{s_2} \pm q_{s_3}}{C_{m,s_1,s_2,s_3}} + \cdots + \sum_{\substack{s_1=1\\ s_1\ne m}}^{2}\sum_{\substack{s_2=s_1+1\\ s_2\ne m}}^{3}\cdots\sum_{\substack{s_{n-1}=s_{n-2}+1\\ s_{n-1}\ne m}}^{n}\frac{q_m \pm q_{s_1} \pm q_{s_2} \pm \cdots \pm q_{s_{n-1}}}{C_{m,s_1,s_2,\ldots,s_{n-1}}}. \quad (9)$$

4) Electrical *Rayleigh dissipation function* Φ_e is defined as a half of instantaneous powers of all electrical energy losses observed in the circuit [13].

Thus, taking into account the phenomenon of hyperforce (hypervalence) interaction, for the generalized circuit it can be written [14]:

$$\Phi_e = \frac{1}{2}\sum_{s_1=1}^{n}R_{s_1}i_{s_1}^2 + \frac{1}{2}\sum_{s_1=1}^{n-1}\sum_{s_2=s_1+1}^{n}R_{s_1,s_2}\left(i_{s_1} \pm i_{s_2}\right)^2 + \frac{1}{2}\sum_{s_1=1}^{n-2}\sum_{s_2=s_1+1}^{n-1}\sum_{s_3=s_2+1}^{n}R_{s_1,s_2,s_3}\left(i_{s_1} \pm i_{s_2} \pm i_{s_3}\right)^2 + \cdots + \frac{1}{2}\sum_{s_1=1}^{1}\sum_{s_2=s_1+1}^{2}\cdots\sum_{s_n=s_{n-1}+1}^{n}R_{s_1,s_2,\ldots,s_n}\left(i_{s_1} \pm i_{s_2} \pm \cdots \pm i_{s_n}\right)^2, \quad (10)$$

where $R_{s_1,\ldots,s_\nu}$, $\left(2 \le \nu \le n\right)$ – ν-loop mutual active resistances and R_{s_1} – self-resistance of the corresponding independent loop.

Therefore, based on (10), for an arbitrary m-th independent loop we obtain

$$\frac{\partial \Phi_e}{\partial i_m} = R_m i_m + \sum_{\substack{s_1=1\\ s_1\ne m}}^{n}R_{m,s_1}\left(i_m \pm i_{s_1}\right) + \sum_{\substack{s_1=1\\ s_1\ne m}}^{n-1}\sum_{\substack{s_2=s_1+1\\ s_2\ne m}}^{n}R_{m,s_1,s_2}\left(i_m \pm i_{s_1} \pm i_{s_2}\right) + \sum_{\substack{s_1=1\\ s_1\ne m}}^{n-2}\sum_{\substack{s_2=s_1+1\\ s_2\ne m}}^{n-1}\sum_{\substack{s_3=s_2+1\\ s_3\ne m}}^{n}R_{m,s_1,s_2,s_3}\left(i_m \pm i_{s_1} \pm i_{s_2} \pm i_{s_3}\right) + \cdots + \sum_{\substack{s_1=1\\ s_1\ne m}}^{2}\sum_{\substack{s_2=s_1+1\\ s_2\ne m}}^{3}\cdots\sum_{\substack{s_{n-1}=s_{n-2}+1\\ s_{n-1}\ne m}}^{n}R_{m,s_1,s_2,\ldots,s_{n-1}}\left(i_m \pm i_{s_1} \pm i_{s_2} \pm \cdots \pm i_{s_{n-1}}\right). \quad (11)$$

5) The obtained relationships (7), (9) and (11) are substituted into the equation system (5), where the corresponding regrouping of the components of multiple sums in the obtained conglomerate makes it possible to find the equation system that, by its structure, can simultaneously reflect the composition, topology and tectology of the electric circuit with lumped parameters generalized by the number of the degrees of freedom, which is built taking into account the phenomenon of hyperforce (hypervalence) interaction.

These equations will be further referred to as *structural equations* of the generalized electric circuit in the first system of generalized electrical coordinates.

The structural equations of motion of the generalized electrical circuit in the first system of generalized electrical coordinates have the following form [14]:

$$\left(L_m \frac{di_m}{dt} + R_m i_m + \frac{q_m}{C_m}\right) + \sum_{\substack{s_1=1 \\ s_1 \neq m}}^{n} \left[L_{m,s_1} \frac{d}{dt}\left(i_m \pm i_{s_1}\right) + R_{m,s_1}\left(i_m \pm i_{s_1}\right) + \frac{q_m \pm q_{s_1}}{C_{m,s_1}} \right] +$$
$$+ \sum_{\substack{s_1=1 \\ s_1 \neq m}}^{n-1} \sum_{\substack{s_2=s_1+1 \\ s_2 \neq m}}^{n} \left[L_{m,s_1,s_2} \frac{d}{dt}\left(i_m \pm i_{s_1} \pm i_{s_2}\right) + R_{m,s_1,s_2}\left(i_m \pm i_{s_1} \pm i_{s_2}\right) + \frac{q_m \pm q_{s_1} \pm q_{s_2}}{C_{m,s_1,s_2}} \right] +$$
$$+ \cdots + \sum_{\substack{s_1=1 \\ s_1 \neq m}}^{2} \sum_{\substack{s_2=s_1+1 \\ s_2 \neq m}}^{3} \cdots \sum_{\substack{s_{n-1}=s_{n-2}+1 \\ s_{n-1} \neq m}}^{n} \left[L_{m,s_1,s_2,\ldots,s_{n-1}} \frac{d}{dt}\left(i_m \pm i_{s_1} \pm i_{s_2} \pm \cdots \pm i_{s_{n-1}}\right) + \right. \tag{12}$$
$$\left. + R_{m,s_1,s_2,\ldots,s_{n-1}}\left(i_m \pm i_{s_1} \pm i_{s_2} \pm \cdots \pm i_{s_{n-1}}\right) + \frac{q_m \pm q_{s_1} \pm q_{s_2} \pm \cdots \pm q_{s_{n-1}}}{C_{m,s_1,s_2,\ldots,s_{n-1}}} \right] = e_m,$$

$m = 1, 2, \ldots, n.$

It should be added that relative to the given system of coordinates the system of structural equations (12) of the generalized electrical circuit as well as its generalized structural scheme (see Fig. 1) is the most logically strong for today and deductively covers the widest class of electric circuits, since it is obtained taking into account the phenomenon of hyperforce (hypervalence) interaction. In particular, said basic element deductively subordinates also the system of structural equations proposed in [13],

$$\left(L_m \frac{di_m}{dt} + R_m i_m + \frac{q_m}{C_m}\right) + \sum_{\substack{s_1=1 \\ s_1 \neq m}}^{n} \left[L_{m,s_1} \frac{d}{dt}\left(i_m \pm i_{s_1}\right) + R_{m,s_1}\left(i_m \pm i_{s_1}\right) + \frac{q_m \pm q_{s_1}}{C_{m,s_1}} \right] = e_m, \quad m = 1, 2, \ldots, n, \tag{13}$$

since the presented equations (13) are only a separate case of equations (12).

6. Structural equations of the generalized electrical circuit in the second system of the generalized coordinates, taking into account the phenomenon of hyperforce (hypervalence) interaction

For the given structural equation, we will use *Maxwell – Lagrange equations* written *in the second system* of generalized electrical coordinates:

$$\frac{d}{dt}\frac{\partial W_e}{\partial \varphi_m} + \frac{\partial W_м}{\partial \psi_m} + \frac{\partial \Phi_e}{\partial \varphi_m} = J_m, \quad m = 1, 2, \ldots, n, \tag{14}$$

where W_e, $W_м$, Φ_e – energy functions of the generalized electrical circuit.

Taking into account the phenomenon of hyperforce (hypervalence) interaction and according to the above procedure, based on (14), we obtain structural equations of the generalized electrical circuit that in the second system of the generalized coordinates have the form of [14]:

$$\left(C_m \frac{du_m}{dt} + G_m u_m + \frac{\psi_m}{L_m}\right) + \sum_{\substack{s_1=1 \\ s_1 \neq m}}^{n} \left[C_{m,s_1} \frac{d}{dt}\left(u_m \pm u_{s_1}\right) + G_{m,s_1}\left(u_m \pm u_{s_1}\right) + \frac{\psi_m \pm \psi_{s_1}}{L_{m,s_1}} \right] +$$
$$+ \sum_{\substack{s_1=1 \\ s_1 \neq m}}^{n-1} \sum_{\substack{s_2=s_1+1 \\ s_2 \neq m}}^{n} \left[C_{m,s_1,s_2} \frac{d}{dt}\left(u_m \pm u_{s_1} \pm u_{s_2}\right) + G_{m,s_1,s_2}\left(u_m \pm u_{s_1} \pm u_{s_2}\right) + \frac{\psi_m \pm \psi_{s_1} \pm \psi_{s_2}}{L_{m,s_1,s_2}} \right] + \cdots +$$

$$+\cdots+\sum_{\substack{s_1=1\\ s_1\neq m}}^{2}\sum_{\substack{s_2=s_1+1\\ s_2\neq m}}^{3}\cdots\sum_{\substack{s_{n-1}=s_{n-2}+1\\ s_{n-1}\neq m}}^{n}\left[C_{m,s_1,s_2,\ldots,s_{n-1}}\frac{d}{dt}\left(u_m\pm u_{s_1}\pm u_{s_2}\pm\cdots\pm u_{s_{n-1}}\right)+\right.$$
$$\left.+G_{m,s_1,s_2,\ldots,s_{n-1}}\left(u_m\pm u_{s_1}\pm u_{s_2}\pm\cdots\pm u_{s_{n-1}}\right)+\frac{\psi_m\pm\psi_{s_1}\pm\psi_{s_2}\pm\cdots\pm\psi_{s_{n-1}}}{L_{m,s_1,s_2,\ldots,s_{n-1}}}\right]=J_m, \quad (15)$$

$m=1,\,2,\ldots,n.$

Thus, structural equations are obtained taking into account the phenomenon of hyperforce (hypervalence) interaction. The equations bijectively correspond to the elements of the generalized structural scheme of Fig. 1 and have the highest for today generalization degree among the electrical circuits built in the second system of generalized coordinates, in particular, electrical circuits proposed in [13],

$$\left(C_m\frac{du_m}{dt}+G_m u_m+\frac{\psi_m}{L_m}\right)+\sum_{\substack{s_1=1\\ s_1\neq m}}^{n}\left[C_{m,s_1}\frac{d}{dt}\left(u_m\pm u_{s_1}\right)+G_{m,s_1}\left(u_m\pm u_{s_1}\right)+\frac{\psi_m\pm\psi_{s_1}}{L_{m,s_1}}\right]=J_m, m=1,\,2,\ldots,n,$$

where the latter, as their correlation with system (15) proves, are only one among many possible cases of equations (15) and only under certain conditions.

Conclusions

The paper has described the revealed general natural phenomenon of hyperforce (hypervalence) interaction. Its taking into account has made it possible to build, based on mathematical investigation and analysis of Lagrange – Maxwell equations, the electrical circuit generalized by the number of the degrees of freedom with the highest generalization degree for today as well as to form its generalized structural scheme and obtain structurally defined system of its differential equations of motion in the first and second systems of generalized coordinates.

The obtained results have both special engineering and generally natural significance.

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