INVESTIGATION OF POSSIBILITIES TO APPLY THE METHOD OF TENSOR TRANSFORMATIONS OF ELECTRIC NETWORKS IN SYNTHESIS OF CONTROL STRUCTURES IN AGRO-INDUSTRIAL COMPLEX

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Abstract. At present the technical and technological possibilities, achieved in the field of agriculture, communications and computing technology, allow to implement quickly reconfigurable (adaptive) agro-industrial complexes. Situational transformation in the management (organization) of economic processes ensures a previously unattainable level of agricultural efficiency. To manage such agro-industrial complexes-transformers, automated control systems (ACS) are required, which have also adaptive properties. The concept of creating such an automated control system assumes an implementation of the principle of modularity and flexible changes in the structure of the management hierarchy, capacities, tasks and functions for geographically distant decision-making centres and performers. One of the key links that determines successful implementation of such an adaptive automated control system is the technology of adaptation (synthesis) of temporary management structures of the agro-industrial complexes. The article includes a formulation of the problem of synthesizing the structure of a temporarily created management system for the territorially distributed agro-industrial complex. It is proposed to solve this problem on the basis of the methodology of tensor transformations of the electrical networks of G. Krohn. Krohn's tensor approach, being a set-theoretic and algebraic synthesis of topologies in the form of tensor transformations, allows for a quantitative description of the intra-system connections for the analysed (synthesized) structures of a wide class of systems, including the management structures of agro-industrial complexes. In contrast to the alternative methods, used for the analysis and synthesis of structures (the flow models and the queueing theory, the graph theory and topology modelling), Krohn's tensor methodology combines both the network interactions and a parametric representation of the network structure. This allows direct formulation of the problems of synthesizing structures that satisfy the behaviour invariant and the given criterion of optimality of the intra-system processes. The synthesis of the new control system for the agro-industrial complex is carried out by means of a tensor transformation of the original electrical network (the system being transformed) into a network that satisfies the established criterion of its behaviour invariant. To transform the network, a special synthesis tensor is applied, the type of which is determined by the selected invariant of the network behaviour. The article presents a general formulation of the problem of synthesizing a management structure that ensures an unchanged total labour intensity of the management functions of the officials when their subordination, powers, and amount of the information interaction with the colleagues in discussions change. A possibility is shown of using the method of tensor transformations of the electrical networks for the synthesis of structures of the temporarily created control loops in the agro-industrial complexes.

Keywords: automated control system, control loop, tensor, electrical network, organization, synthesis, agrotechnical process.

Introduction

The introduction of the information technology in agriculture is an urgent need, which is associated with the necessity to increase its productivity at limited global agricultural land areas. The efficiency of the use of information technologies is determined [1; 2]: firstly, by the progress in the improvement of the means of communication, contacts, processing and storage of information, miniaturization and expansion of the range of the information sensors, reduction in the cost of using the positioning tools with their increased accuracy; and, secondly, by the development of technologies, based on the use of adaptive actuators, machines and technical and technological systems, capable of carrying out technological processes in the mode of permanently changing input parameters of the state of the object of work, the system itself and the purpose of the application (optimization parameters).

In the last decade there takes place rapid growth of the market of automated agricultural management systems. The level of sophistication of the information technologies, used here, can be appraised by [3] and [4]. These platforms are typical and have all the characteristic features of the projects, implemented in the field of automation of the agricultural objects. In terms of systems

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engineering, the main characteristic features of these systems are: unification of objects into a single information network; exchange and management of data, based on the Internet of Things and network technologies; the use of the "cloud" platforms with a distributed topology of the information sources and consumers, the data processing and storage centres [5; 6]. Due to the divided collection, processing and storage of information, high operational reliability is ensured, as well as the resistance of the system to negative environmental impacts. In functional terms the following has been implemented: monitoring of the actual state of the technological processes, the use of the means and resources; forecasting the parameters of the condition of the control object at various levels of information generalization. The information processing takes place in real time (in the tracking mode).

In addition, in [3; 4], incidentally, it can also be said about the other software products, such procedures as:

- formation of parameters and transmission of commands to the performers to eliminate identified deviations from technological norms or the plan for carrying out activities;
- formation of decisions on planning the activities of the organization in the form of tasks of optimal or priority distribution of the limited resources and determination of the order of application of the available means;
- adaptation of the automated control system in the event of abnormal control situations (establishment and adjustment of temporary control loops, relevant to the current situation).

If the first two directions can be developed within the framework of the existing platforms of the corporate management systems, then the direction of the adaptation requires significant and labour-intensive reworking of the software of the automated control system (ACS) [7]. The structural changes, associated with the transfer of powers and the formation of management structures on a territorial basis, are embarrassing.

Investigations, aimed at obtaining efficient mechanisms for the adaptation of complex systems were committed for the electric power networks. In [8] a method is proposed for the determination of the operating parameters of the "active" network nodes (including the signs of switching on and off of the connections) in order to regulate the integral characteristics of the electric power grid. That is, adaptation is achieved by changing the constants and switching the connections of some nodes of the network.

In [9] it is proposed to optimize the parameters of a large energy system by solving a number of optimization problems that represent a decomposition of a single optimality criterion. This approach is an evolvement of [8] since it allows scaling the dimension of the problem being solved. Besides, here are also limited possibilities to synthesize the options of alternative network structure.

The principles of constructing geographically distributed information monitoring systems that are resistant to destructive impacts are presented in [10]. Better stability of the system is achieved through the redistribution of the functions between the elements of the system and the formation of temporary management contours. However, the presented results are not supported by mathematical models and formalized methods of transformation of ACS.

In [11] a general formulation of the problem of designing and optimizing the structure of a distributed information system is proposed in terms of the set theory. An M-graph of the parametric space designing is described. However, to translate the problem into practical terms, as also for [10], it is still necessary to work out the corresponding formalized methods.

A more detailed approach to the solution of the problems of forming temporary management structures for geographically distributed systems is demonstrated in [12]. A procedure is proposed to build a structure of the synthesis, using a library of components and cognitive maps of their target linkage. However, in addition, there is left out of consideration the task of adapting procedural regulations for decision-making centres to be included into temporary management circuits.

In [13] it is proposed to synthesize procedural regulations for various management bodies, based on general and partial ontologies of activity. The synthesis of procedural regulations for an established decision-making centre is accomplished by the method of successive detailing of the elements of general ontology, using network frames, representing private ontologies. However, the synthesis problem in the work is formulated only in general terms, without proposing procedures, suitable for the solution of practical problems.

In [14] it is proposed to solve the problem of synthesis of the structure for a temporarily created control loop as a problem of tensor transformation of a primitive electrical network, using the methods of [15]. This approach is quite universal and flexible. In addition, further research is needed on the formalized description of the criteria for the specified behaviour of the transformed network and the derivation of a tensor for the synthesis of a new network on its basis.

Thus, to solve the problem how to adapt ACS of an agricultural complex, it is necessary to use the concept of territorially distributed systems. In this case, the following tasks must be solved: 1) synthesis of temporary management structures, relevant to the current situation, with a simultaneous distribution of the functions and tasks between the objects inside the system; 2) synthesis of procedural regulations for the decision-making centres, included into the temporary management structures.

This article is devoted to the solution of the first problem – the synthesis of temporary management structures, depending on the tasks to be solved and the management conditions.

To synthesize a management structure with established properties, it is proposed to use the methods of the tensor analysis and synthesis of electrical networks by G. Krohn [15].

The description of the proposed method in the article is fulfilled for the territorially distributed agrotechnical information system (TDAIS) [16]. The problem statement of the management structure synthesis is formulated as a problem of synthesis of an electric network that meets the established criterion of the network behaviour. The interpretation of the electric network is described as a management structure. Tensor relations are given with the help of which the original electric network (a changeable management structure) is transformed into a new network (a synthesized management structure).

Materials and methods

Definition of a territorially distributed information agrotechnical system with temporarily created management structures.

A geographically distributed information agrotechnical system (TRIAS) is a set of organizational structures, software, hardware and telecommunications tools, algorithms, procedural regulations, technologies, databases and data banks and the knowledge that operate in a single information space and are intended for adaptive automated management of agrotechnical processes in an agricultural region [16].The main distinguishing feature of TRIAS is the possibility of creating temporary management structures based on territorial and functional criteria. The composition of subjects and objects in the system of agricultural activities, their relationships, information links (management structure) can change significantly depending on the nature of the tasks being solved, as well as on the established norms of time and conditions of economic activity.

Since there are many options for formation of temporary management structures of the agrotechnical complex that will solve the same problems, there is a problem of choosing the best alternative from a variety of the possible management systems.

The management structure as a multi-coil electrical network, its formation, using a synthesis tensor.

The management structures can be conveniently interpreted as multi-coil electrical networks. In contrast to other types of non-electrical networks, an electrical network is always surrounded by a dynamic electromagnetic field, created by itself and extending to infinity in all directions. Using the model of induction and self-induction in the branches of an electrical network, it is convenient to describe various types of intra-system connections between the elements of the structure under consideration (organizational topology). That is, if we interpret the control system as an electrical network, then the subjects of the control system are essentially electrical coils, each of which has its own impedance (inductive resistance). When the electric current is flowing or voltage is applied to the branches of the network, the coils interact with each other, inducing current in the adjacent coils. This interaction is characterized by the impedances of the cross (inductive) connections. That is, the electrical impedances of the coils can be considered as some numerical metrics:

- the complexity of the management functions of the subjects in the control system under consideration (proper impedances, diagonal elements of the impedance tensor);

- the cross-influence of subjects on the complexity of control, committed by their colleagues (impedances of cross-inductive connections of coils).

The control process is quantitatively described by Ohm's law, written in the form of a system of the voltage equations or the current equations:

$$e = z \cdot i , \tag{1}$$

$$I = Y \cdot E , \tag{2}$$

where e , i – vectors of the contour network voltages and currents, respectively;
E , I – vectors of the nodal network applied voltages and currents;
z , Y – network impedance and admittance tensors.

In this case, as applied to the control systems, the current strength is interpreted as a flow of control actions, decisions, documents (control information). Voltage is like a productive force, the number of decision-makers, concentrated in the control system subject under consideration.

Based on (1), an increase in the complexity of decision-making leads to a decrease in the value of the flow of the control information, passed through the considered subject of the control system, if its productive force remains unchanged.

For the current equation (2), its interpretation is presented in a reverse order relative to (1). Admittance **Y** is a value, opposite to the impedance. That is, it may be interpreted as a magnitude of the useful effect in the form of a flow of the management information, which is created by a unit of the productive force (one manager). Then an increase in the useful return (labour productivity) for any subject of management leads to an increase in the flow of the management information with an unchanged productive force of the subject. Or – to a reduction in the number of forces involved while maintaining the volume of management tasks to be solved.

The structure of the control system is described using the connection tensor which establishes a connection between the coils of a primitive electrical network and the axes (geometric objects) of the connected network

$$\mathbf{C} = \begin{matrix} & \begin{matrix} 1' & \cdots & n' \end{matrix} \\ \begin{matrix} 1 \\ \vdots \\ n \end{matrix} & \begin{bmatrix} \delta_{1,1} & \cdots & \delta_{1,n} \\ \vdots & \delta_{i,j} & \vdots \\ \delta_{n,1} & \cdots & \delta_{n,n} \end{bmatrix} \end{matrix}, \tag{3}$$

where $\delta_{i,j}$ – element of the connection tensor which typically takes integer values: –1; 0; + 1;
$i = 1, \dots, n$ – indices of the coils of the primitive network where n is the number of coils that make up the primitive network;
$j = 1', \dots, n'$ – indices of the axes (geometric objects) of the connected network where n' is the number of geometric objects of the connected network. The dashes here indicate that the parameter in question belongs to the connected network.

The values of the elements of the connection tensor C are determined on the basis of compiling the current (voltage) balance equations for nodes (circuits) of the primitive and the connected networks according to the first (second) Kirchhoff's law [15].

That is, the connected tensor allows to make a transition from the primitive network, consisting of short-circuited individual coils to the connected network, where geometric objects (contours and nodal pairs) are formed from the coils of the primitive network.

To make a transition from the initial connected network (α-network) to the synthesized, also connected network (β-network), the synthesis tensor $\mathbf{C}'_\sigma$ [15] is used:

$$\mathbf{z}'_\beta = \mathbf{C}'^{\mathrm{T}}_\sigma \mathbf{z}'_\alpha \mathbf{C}'_\sigma , \tag{4}$$

where $\mathbf{C}'_\sigma$ – synthesis tensor which is formed from the condition of invariance of the behaviour of the original and the synthesized networks according to the selected criterion;
$\mathbf{z}'_\alpha, \mathbf{z}'_\beta$ – tensors of cross and proper impedances of the coils of the original and synthesized networks, respectively.

The synthesis tensor for the criterion of constancy of the input impedance of the electrical network (constancy of the total labour intensity of control in the control structure) has the form [15]:

$$\mathbf{C}'_\sigma = \begin{matrix} & 1^\beta & 2^\beta & 3^\beta \\ 1^\alpha & \mathbf{I} & 0 & \mathbf{C}_3^1 \\ 2^\alpha & \mathbf{C}_1^2 & \mathbf{C}_2^2 & \mathbf{C}_3^2 \\ 3^\alpha & 0 & 0 & \mathbf{C}_3^3 \end{matrix}, \tag{5}$$

where $\mathbf{I}$ – identity matrix;

$\mathbf{C}_j^i = \left\{k_{j\,s,p}^i\right\}$ – fragments of the synthesis tensor, recorded for the coil groups of the initial connected network (α-network) during the transition to the synthesized connected network (β-network).

Here $0 \le k_{j\,s,p}^i < +\infty$ are the elements of the synthesis tensor when considering the transition from the geometric objects of the α-network of the i-th group to the objects of the β-network of the j-th group; s,p are the indices of the coils that form the i-th and j-th groups of the initial and the synthesized networks, respectively.

Let us consider the following groups of coils:

- group No. 1: the input objects – circuits, nodal pairs to which external exciting voltages and currents are applied;
- group No. 2: the output objects – circuits, nodal pairs to which load currents and voltages are applied;
- group No. 3: intermediate contours and nodal pairs.

The impedance tensor of the connected synthesized network $\mathbf{z}'_\beta$ characterizes the ongoing processes in terms of the geometric objects of the connected network. However, it is more informative to describe these processes by tying them to individual coils of the network. To obtain the characteristics of the synthesized network in the parameters of its individual coils, rather than geometric objects, the primitive synthesis tensor $\mathbf{C}_\sigma$, is used, which is defined as

$$\mathbf{C}_\sigma = \mathbf{C}_\alpha \mathbf{C}'_\sigma {\mathbf{C}_\beta}^{-1}, \tag{6}$$

where $\mathbf{C}_\alpha$, $\mathbf{C}_\beta$ – connection tensors that form from the primitive α-network and β-network, respectively, their connected networks;

$\mathbf{C}'_\sigma$ – synthesis tensor (5).

If the primitive synthesis tensor is known, then instead of (4) we can write

$$\mathbf{z}_\beta = {\mathbf{C}_\sigma}^{\mathrm{T}} \mathbf{z}_\alpha \mathbf{C}_\sigma, \tag{7}$$

where $\mathbf{z}_\alpha$, $\mathbf{z}_\beta$ – impedance tensors of the primitive initial and primitive synthesized networks, respectively.

The currents and voltages in individual coils of the synthesized network, if the impedance tensor of the primitive network (7) is known, are calculated as

$$\boldsymbol{i}_\beta = \boldsymbol{C}_\beta \boldsymbol{i}'_\beta, \tag{8}$$

$$\boldsymbol{e}_\beta = \boldsymbol{z}_\beta \boldsymbol{i}_\beta, \tag{9}$$

where $\boldsymbol{i}'_\beta$ – vector of currents in the branches of a connected synthesized network when it is excited by external currents;

$\boldsymbol{i}_\beta$ – vector of currents in individual coils of the synthesized network;

$\boldsymbol{e}_\beta$ – vector of voltages on individual coils of the synthesized network.

Having the following data for a synthesized electrical network (the management structure): proper impedances of coils (the labour intensity of the management processes for individual subjects of the management system); impedances of cross (inductive) connections (mutual influence of subjects on the labour intensity of their management processes); currents in the individual coils (implemented information flows); voltages at the coil terminals (forces involved in solving the management problems) it is possible to carry out a comparative analysis of alternative management structures of agrotechnical complexes.

Results and discussion

The proposed method for synthesizing the management structures of agrotechnical complexes uses the apparatus of tensor transformations of the electrical network characteristics. The type of the applied synthesis tensor, with the help of which it is proposed to implement transition from the (initial, input) original network to the network to be synthesized, is determined by the selected criterion of the network behaviour. In the article, this is the criterion of invariance of the input impedance of the original and synthesized networks. Strictly speaking, with the help of this tensor, using (4), a set of alternative synthesized networks is formed that have the same property of the input impedance invariance. A specific network variant is selected by changing the values of the elements of the synthesis tensor in accordance with the established optimality criterion in terms of the feasibility of the synthesized management structure.

The proposed approach has an advantage over the methods that use simple or directed enumeration of alternatives since it makes use of a directed enumeration of a set of alternatives, previously reduced by means of a synthesis tensor. Only those alternatives are considered that satisfy the criterion of invariance of the network behaviour. Besides the criterion of the input impedance invariance (invariance of the total complexity of the control process), other criteria may also be considered:

- constancy of the output current (load current) (constancy of the performance of the control system);
- constancy of the input or output voltage (application constancy of forces in the control centres of the upper or lower level).

Further development of the method consists of developing algorithms for directed search on a set of elements of the applied synthesis tensors and formalizing the criteria of optimality and constraints (conditions) of the feasibility of the synthesized management structures.

Conclusions

1. Software products currently offered on the market of agricultural automated control system (ACS), while having a number of advantages (cloud technologies, Internet of things, big data), are not without drawbacks. The main disadvantages are the limited possibilities for adaptation when creating temporary management structures.
2. The task of synthesizing the management structure of an agrotechnical complex with particular properties can be solved as a task of synthesizing an electrical network, using a synthesis tensor according to a pre-set criterion of invariance of the network behaviour.
3. The proposed approach allows for a quantitative comparative analysis of the synthesized management structures. In this case, the task becomes relevant of a formalized description in terms of electrical networks of the optimality criteria, restrictions, and conditions in terms of the feasibility of the management systems.

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