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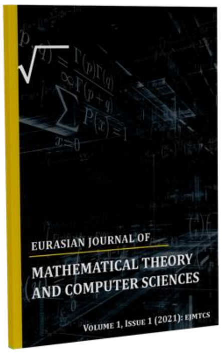

THE MODEL OF INTELLIGENT CONTROL OF THE STATE OF PARAMETERS IN DIGITAL POWER GRIDS

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ABSTRACT

In this article, the introduction of intelligent control of the state of parameters in digital power grids. When new realities arise in our lives, the first thing we do is agree on names and terminology. It is impossible to have a discussion if its participants understand different processes under the same names or the same subjects of discussion have different conceptual names. This is especially true for new areas of activity that have arisen in the process of developing well-established practices with generally accepted terminology. It is the novelty of such a direction of development of society as digitalization that causes the blurring of the boundaries between the terms "Automation" and "Digitalization". With all the increased interest in the digital transformation of the electric power industry, the main attention should be paid to the introduction of new progressive technologies in energy production and the improvement of electric and thermal energy markets. Currently, the electricity (capacity) market is mainly used to collect financial resources from industrial consumers, replacing budgetary funds. The electricity tariff of the wholesale market is at least half formed by non-market methods. Everything else is non–market fees. The transition to digital energy without modernizing and improving markets is a risk of subsequent alterations

with expensive costs.

Introduction

Digital electric power industry is the economic activity of industry entities using information technology.

The reasons that encourage the Russian electric power industry to switch to digital technologies are as follows:

The condition for successful modernization, technical re-equipment, and updating of production systems is the use of information technology, the creation of information and telecommunications infrastructure, and the development and implementation of intelligent algorithms for managing technical facilities.

The strategic objective is to modernize the Russian energy sector, which has a low technological level. The scale of the problems in this area has been actualized by a lot of scientific research, development of possible approaches to solving global and particular problems in the field of energy automation [18, 22]. The use of information technologies and the development of intelligent power grid management systems using new equipment regulating the parameters of power grids will significantly reduce the role of the human factor in decision-making, personnel errors in managing normal operating modes of power grids, as well as the risks of emergencies. The digital transformation of the energy complex is based on the application of innovative technologies for data collection, processing and exchange, remote monitoring of power supply reliability, and intelligent management of energy facilities. Huge amounts of data require the use of intelligent processing technologies; the growing requirements for the reliability of the functioning of power grids and the quality of electricity require the development of new technologies for intelligent control of power systems to increase the stability of operating modes [2, 3, 6, 7].

The transition to digital technologies is one of the leading trends in modern electric power systems. Digitalization of electrical distribution and supply networks will ensure reliable operation, increase the quality of supplied electricity and throughput, help to quickly eliminate short-circuit currents and optimize operating costs [14, 17, 20]. Distributed automation, remote monitoring of the system as a whole, unified management of its components – all this will be possible thanks to the transition to an intelligent control system based on an open data platform.

Modernized electric networks most often provide electricity to industrial enterprises, public and residential buildings. Now, traditional electric power equipment does not correspond to new economic and operational solutions [4, 5, 10].

Now, traditional electric power equipment does not correspond to new economic and operational solutions [10-11]. At the same time, the number of consumers is increasing every year both at industrial facilities and in the housing and communal sector. At the same time, dispatching control on the automated process control system (APCS), which now exists, does not cope with accidents that occur during operation, which in turn lead to failures of network segments, exactly as to financial, economic and social consequences [12, 14, 17, 18].

The intellectualization of energy systems in the Republic of Uzbekistan is a strategically important task, which requires a transition to a new quality of management at all levels of the hierarchical power grid management system. In accordance with the Decree of the President of the Republic of Uzbekistan

"On the strategy for further development and reform of the electric power industry of the Republic of Uzbekistan" dated March 27, 2019, the digital power grid should include the following functionality: topology analysis and calculation of the steady-state mode in the distribution network [1, 11, 12]; automatic voltage regulation in accordance with the schedule of operational dispatch control set by the subject; automated reduction and restoration loads according to the commands of the subject of operational dispatch management, etc.

To solve the problems of the electric power industry and bring it to a new modern level, the concepts of "smart" active adaptive networks (Smart Grid) are being developed. The intellectualization of energy systems includes the development of highly efficient information technologies for collecting, intelligent processing, and transmitting information [10-11], as well as the development of new principles and technologies for managing energy networks. Due to the increase in electricity consumption and requirements for its quality, it is necessary to search for new solutions to ensure efficient operation of power grids at any given time under constantly changing external and internal conditions of its operation [13, 23-25].

Only the creation of digital substations will not lead to the digitalization of the electric power industry. In the digital electric power industry, information and communication technologies must be used not only at individual technical facilities of the industry, but also in the management of electric power systems, as well as in the processes of energy production and provision of services along the entire technological chain from creation to consumption of electric and thermal energy [2, 8, 9].

The digital transformation of energy is a set of measures that includes the formation of a common language and communication space between participants in industry processes.

Digital transformation involves working with a large amount of data. Only one thermal power plant generates about two terabytes of data, of which only 1-2% are used. Today, new technologies have appeared that are designed to make it easier to work with a huge array of data, in terms of not only collection, but also their interpretation: artificial intelligence, cloud (remote) computing, big data technologies.

To ensure the quality of electricity supply to the consumer in distribution electric networks, it is necessary to solve the problem of regulating the values of parameters intended for this purpose of specialized devices in real time [3, 4, 5]. This task requires the development and research of models and algorithms for controlling such devices, as well as the study of the mutual influence of the parameters of the regulating device on the state of the electric network, which is impossible without creating a simulation model of a distribution electric network with the ability to programmatically control the process of determining the state of power grids and programmatically changing the values of parameters and operating modes of the model.

To ensure the quality of electricity, the following tasks must be solved [8, 9, 10, 21, 22, 24, 25]:

- ensuring maximum deviations of consumer voltages from the nominal ones within the tolerance

- Reduction of total energy losses in the network during the transportation of electricity when fulfilling voltage restrictions on consumers within the tolerance.

The reasons for the electric power industry to switch to digital technologies are as follows:

– improving the reliability, manageability, flexibility and observability of electric power systems;

– increasing the requirements for reliability, availability and quality of energy supply from consumers;

– Involvement of distributed generation in energy exchange;

– Formation of decentralized electricity markets;

– increasing the information connection of the electric power industry with other fuel industries fuel and energy complex (gas, coal);

– Development of renewable energy sources, energy storage systems, devices and complexes with controlled consumption;

– Formation of the common electric power market of the member states of the Commonwealth of Independent States.

Research Methods and the Received Results

The most important factor in achieving the maximum economic effect of digitalization of the electric power industry is to increase the efficiency of production process control systems directly in electric power systems and in the power consumption system. To do this, an information and telecommunications infrastructure and a system of hardware and software complexes should be created that will provide the technological possibility of using solutions. Information and communication digital technologies are the basis for the development of the digital economy.

It is also necessary to take measures to improve regulatory legal and regulatory technical documentation, develop the necessary standards, personnel and information support.

The solution of the problem of managing the state of power grids using a complex regulating device is complicated by the following factors:

- Extremely high complexity of obtaining accurate analytical solutions;

- The existence of a set of solutions (different control vectors K) meeting the requirement;

- changing the control coefficient of a separate regulating device changes the state of all elements of the power grid.

However, the fact that the influence of the regulating device on the elements of the electric grid "weakens" as they move away from this regulating device allows us to use various optimization algorithms to solve this problem, in particular, the genetic algorithm [20, 21]. The solution of the problem of "selecting" the optimal vector of control parameters that meets the requirement can be carried out on a simulation model of a distribution electric network.

Because of solving the tasks set, many solutions can be found, while it is possible that acceptable solutions are not found. Figure 1 shows a block diagram of a method for controlling the states of power grids to ensure the quality of electricity using a regulating device.

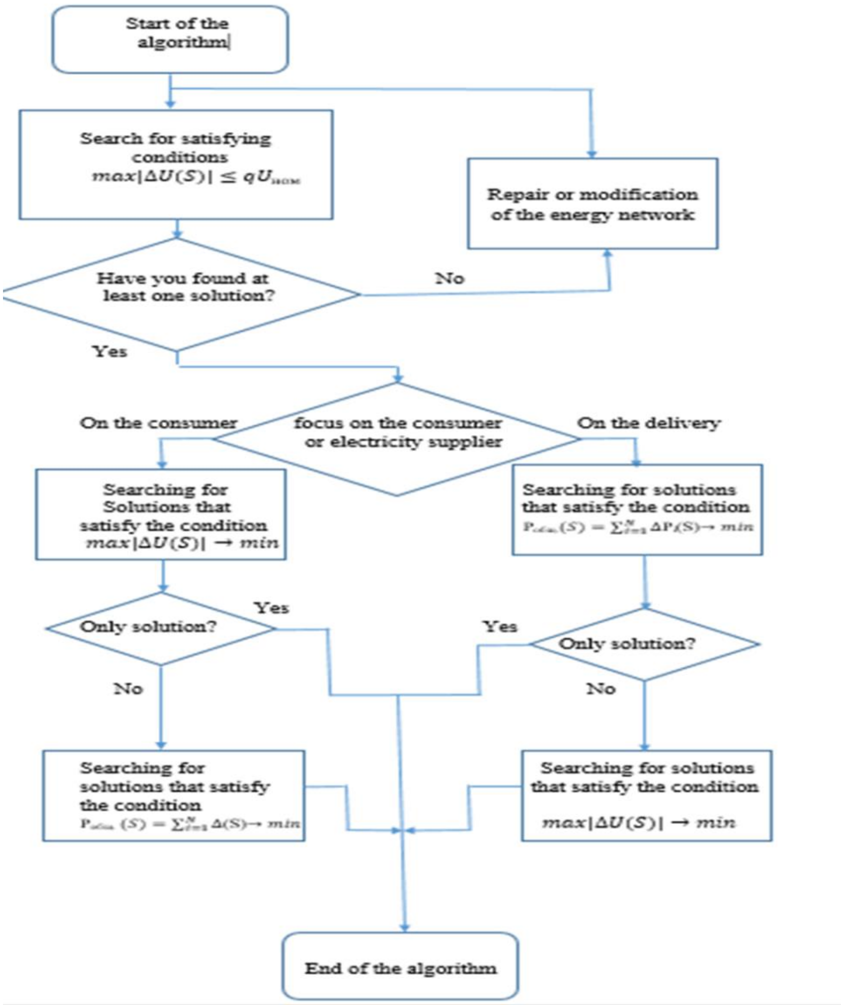

Figure 1 – Flowchart of a method for ensuring electricity quality indicators using a control device.

The lack of solutions may be due to various reasons, such as technical limitations of the control device, limitations or malfunctions of the power grid. In this case, modification or repair of the power grid is required, or the addition of additional regulating devices. Note that the repair or modification of the energy network involves changing the vector of input parameters **R**.

To ensure the quality of electricity, the following options are possible [2, 4, 5, 8, 10, 18, 19, 20, 23, 24, 25]:

- Orientation towards the Consumer of electricity. In this case, the task of minimizing the drawdown of electricity from consumers is solved. In the case of obtaining several solutions to the problem (3), we choose among them the one with the minimum energy loss.

- Focus on the Electricity Supplier. In this case, the problem of minimizing energy loss is solved (2). In the case of obtaining several solutions to the problem, we choose among them the one in which the drawdown of electricity from consumers is minimal.

Development of a simulation model of the electric grid for solving problems of managing its condition.

The conducted research has revealed the possibility of solving the problem of managing the state of power grids in two ways [4, 7, 9, 14, 15, 22]:

- development of an algorithm that is guaranteed to calculate in the required time a set of parameter values of a regulating device that provides voltage values in specified nodes of power grids within the tolerance;

- Adaptation of heuristic algorithms to the solution of the problem of searching for parameter values of the regulating device, with a time limit for obtaining a quasi-optimal solution.

Both approaches require the development of an environment for simulation of power grids (and a simulation model of power grids) of various configurations, providing the ability to programmatically control the modeling process and programmatically change the values of parameters and operating modes of the model.

The task of managing distribution electric networks should be solved for all existing topologies (circuits) of electric networks. Currently, there is no generally accepted classification of electrical networks according to their topology. The names of the existing schemes are as follows: radial, trunk, closed [1, 4, 11, 19, 24], branched circuit, two-way power supply circuit, ring complex closed circuit, multi-circuit configuration [14, 17, 20, 22, 25]. The most versatile and complex in terms of management are electric networks of multi–circuit configuration, further - multi-circuit power grids. In this paper, the problem of managing the state of power grids is solved for electric networks of multi-circuit configuration.

Figure 2 shows an example of a three-level model of a distribution electrical network. The tasks of voltage control and redistribution of power flows in this work are solved for a medium-level distribution electric network (0.4-110 kV).

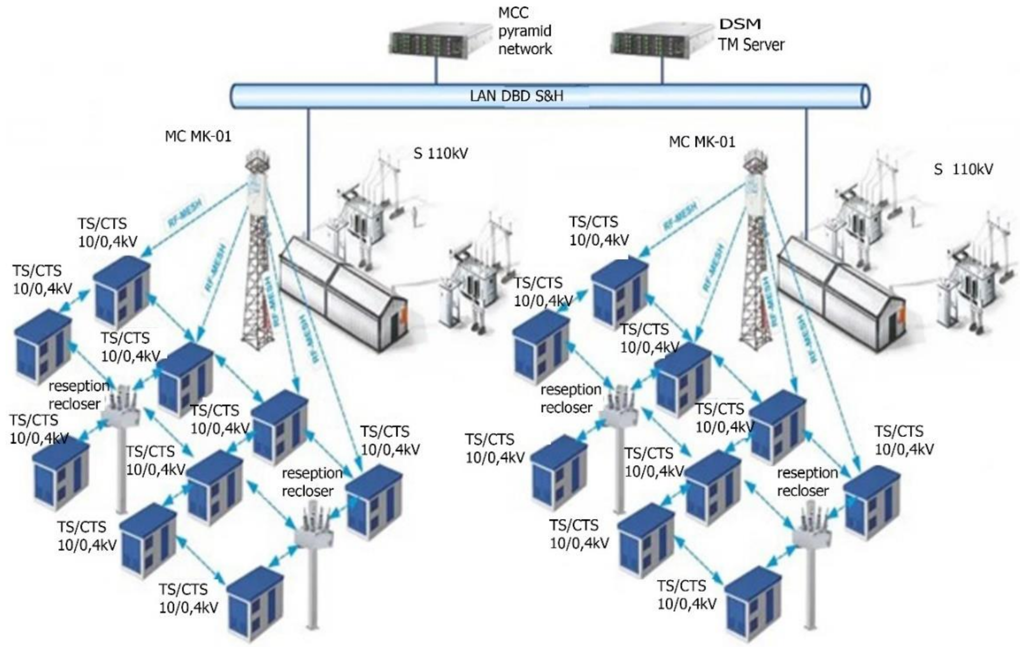

Figure 2 – Block diagram of the distribution network model

The upper-level network contains only voltage sources and step-down transformers. The lower-level network corresponds to the level of the final consumers of electricity.

We will represent the end consumers in the simulation model with step-down transformers and reactive loads.

The medium-level network contains power transmission lines having different sections and lengths, as well as a regulating device to maintain the working conditions of the network. The regulating device in the simulation model being developed are transformers with a complex voltage transmission coefficient [4, 9, 11, 13, 19, 21, 23, 25].

The block diagram of the simulation model is represented by an oriented graph with vertices (nodes) and edges (devices/lines) of various types. Each type of edges and in this work, the calculation of power grids is reduced to solving a system of linear equations of the form.

$$W \cdot U = S$$

In which the matrix of coefficients of the system of linear equations **W** and the vector **S** are formed based on data on the structure and current state of the power grid, and the desired vector **U** is the vector of voltage values in each node of the power grid.

In this case, each value Vi (i=1 n, where n is the number of control device) of the vector of control parameters of the control device V is present in the matrix ***W***:

- in cells located at the intersection of strictly two rows and two (or more) columns, setting the requirement for the values of currents for the input branch of the regulating device and branches, the sum of currents in which is equal to the current in the output branch of the regulating device – the current of the input branch must be greater in *Vi* r z of the current of the output branch (2 cells per each branch, because the current in the nodal potential method is calculated using a weighted potential difference at the ends of the branches);

- in two cells of one of the lines **W**, indicating that the voltage difference at the two nodes of the output branch of the regulating device is *Vi* times greater than the voltage difference at the two nodes of the input branch of the regulating device.

If the potential at one of the nodes of the input branch of the RU is known (for example, zero), then in this case the corresponding rows and columns of the matrix **W** are excluded from the system of equations, which leads to a decrease in the total number of cells containing *Vi*. In any case, there will be at least 3 *Vi* values in three different columns in the matrix **W**.

If all values of vector **V** are given (vector **V** is fully defined), the system of linear equations is solved by standard methods.

Otherwise, the task is to find *m* unknown values of the elements of vector **V** that provide the required voltages in *m* nodes of the electrical network (for example, the voltages of the output branches of the RC), i.e. *m* elements of vector **U** can be assumed to be known (denote them as *ui*), and *n* – *m* elements of vector **U** will be unknown (denote them, as *xi*).

A formalized record of this problem in the form of a system of equations will contain the products of two unknowns, i.e. it will be a system of equations of the second order.

$$\left\{ \begin{array}{l} .....+w_{ij,}v_k u_j + ...+w_{if,}v_k u_f +..... = q_i \\ \\ \\ .....+w_{hd,}v_k x_d +..... = q_h \end{array} \right\}$$

An analysis of the application area for this task has shown that for the case when a regulating device is present in each arc of the spanning tree of an electric circuit graph and controls the voltage values at the ends of these arcs, the values of the parameters of the *vi* RU located in any of the branches of the spanning tree depend only on the values of the parameters of the regulating device in the branches of the tree connecting this branch with one of the leaves.

An arc containing a control device with parameter *vi* divides the spanning tree into two disconnected subgraphs. The values of the parameters of the control devices of the connectivity component containing the root of the spanning tree (before the control devices with parameter *vi*) do not affect the state of the other connectivity component (after the control device with parameter *vi*). It follows from this that the solution of this system of equations is found by sequentially calculating the elements of vector **V** in the order of movement from the leaves of the spanning tree of the graph of the electric circuit to the root of the spanning tree.

Conclusion

The structural and parametric identification of the model has been carried out to solve the problems of intelligent control of the states of power grids. The formalization of the research tasks has been performed – ensuring voltage deviations within the tolerance, minimizing maximum deviations of consumer voltages from nominal values and reducing total energy losses in the network during electricity transportation when limiting the deviation of consumer voltages within the tolerance.

Because of the analysis of the simulation model implementation tools, it was decided to use a high-level programming language and the Matlab modeling software environment. The structural synthesis of the simulation model of power grids of various topologies is performed; the main elements of the electric circuit in the simulation model are described.

After analyzing the results of the implementation, it can be concluded that the following changes will occur with the procedures of business processes.

- Full robotization – the use of technology makes it possible to exclude human participation in any procedure. First, this concerns algorithmized procedures for processing and transmitting information (preparation of reports, summary of data, formation of applications, etc.).

- A hint in making a decision – conducting analytics, making preliminary recommendations, etc. However, the final decision-making in many procedures remains with the person. An example of this kind of procedure can be assistants for the dispatcher during switching, recommendations for the formation of work plans, etc.

- Elimination of the procedure, optimization of the business process path (for example, in terms of paper document flow or an excessive number of approval stages in departments).

- Raising the procedure to a higher level of management: from the area of electrical networks to the branch, from the branch to the Executive Office.

- Insourcing (using internal resources to provide services and works to external contractors (additional services)).

References:

1. The President of the Republic of Uzbekistan No. PP-4249 "On the strategy for further development and reform of the electric power industry of the Republic of Uzbekistan" dated March 27, 2019.
2. Yu. N. Rudenko et al.; edited by Yu. N. Rudenko, V. A. Semenova (2000) Automation of dispatching control in the electric power industry /; Moscow Power Engineering Institute. – Moscow. 648 pages .
3. Y. N. Rudenko et al. (2005) The concept of diagnostics of electrical equipment of substations and power transmission lines of electric networks of JSC FGC UES. 112 p.
4. V. G. Gerasimov, A.V. Dyakova et al. (2002) under the general editorship of V. G. Gerasimov Production, transmission and distribution of electric energy: An electrotechnical handbook. In 4 volumes /; Moscow Power Engineering Institute. – Moscow. 963 p.
5. Chichev, S. I., Kalinin V. F., Glinkin E. I. Information and measurement system of the control center of electric networks. – Moscow: Mashinostroenie, 2009. – 176 p.

6. Chichev, S. I., Kalinin V. F., Glinkin E. I. Control and management system of electrical equipment of substations. – Moscow: Publishing house "Spectrum", 2011. – 141 p.
7. Chichev, S. I., Kalinin V. F., Glinkin E. I. Information and measurement system of an electric grid company. – Moscow: Publishing House "Spectrum", 2011. – 156s.
8. Chichev, S. I., Kalinin V. F., Glinkin E. I. Corporate integrated control system for the distribution grid complex. – Moscow: Publishing house "Spectrum", 2012. – 228 p.
9. Chichev, S. I., Kalinin V. F., Glinkin E. I. Infocommunication networks of the main power grids of the Center. – Moscow: Publishing house "Spectrum", 2013. – 200 p.
10. http://www.ni.com/ru-ru/shop/electronictestinstrumentation/application-software-for-electronic-test-and-instrumentation-category/whatismultisim.
11. http://bwrcs.eecs.berkeley.edu/Classes/IcBook/SPICE.
12. https://www.eremex.ru
13. http://www.spectrum-soft.com/index.shtm
14. http://https://www.analog.com/en/designcenter/design-tools-and-calculators/ltspice-simulator.html
15. http://www.ti.com/tool/tina-ti
16. https://www.autodesk.ru/products/autocad/included-toolsets/autocad-electrical
17. http://qucs.sourceforge.
18. http://www.cadence.com/products/orcad/index.aspx
19. Loskutov A., Loskutov A., Zyrin D., Vukolov V. (2016) Analysis of different topological structures of electric power distribution for the cities and elaboration of method of reducing value of the short-circuit current based on algorithm of dividing network // 2016 2nd International Conference on Industrial Engineering, Applications and Manufacturing. 2016. – P. 7911465.
20. Loskutov A (2016). Development and research of a flexible intelligent electrical network of medium voltage, based on a hexagonal structure / / Loskutov A., Loskutov A., Zyrin D. // International Journal of Applied Engineering Research, Vol. 11, Issue 11. 2016. – P. 7395-7401.
21. Meshcheryakov I. I. (2019) Types of electrical network configurations: http://electricalschool.info/main/elsnabg/642-tipy-konfiguracii.html
22. Rogulina L. G., Levin D.N. (2008) Structural and topological synthesis of electric networks // Telecommunication. No.8. 2008. – pp. 30-33.
23. Dimitris Bertsimas, Eugene Litvinov, Xu Andy Sun, Jinye Zhao, Tongxin Zheng (2013). Adaptive Robust Optimization for the Security Constrained Unit Commitment Problem. //IEEE Transactions on Power Systems. Volume 28.Issue: P.52-63.
24. Korsunov P. Yu., Morzhin Yu. I., Popov S. G. (2011) Development Of The Concept Of "Digital Substation". Agreement no. And-11-41/10 / JSC "NTCE". – Moscow. 248 p .
25. Swami M. Thulasiraman K. Graphs, (1984) Networks and algorithms. Moscow: Mir. 454 P.