Розглянута з одного боку змінна система електропостачання, а з другого – нестабільна система електроспоживання. В рівновагу системи можуть привести лише процеси, що в них протікають під дією взаємозв'язаних зовнішніх і внутрішніх чинників. Використані мережі Петрі та теорія графів. Встановлено, що на початку формуються основні чинники, які визначають ефективність електропостачальних систем, далі за допомогою орграфу будується модель процесів та виконується оптимізація. Отримані результати оптимізації важливі при проектуванні та експлуатації електроенергетичних мереж, сприяють зменшенню енергетичних втрат

Ключові слова: електроенергетичні мережі, електропостачальні системи, ефективність, електроспоживання, електропостачання, чинники енергетичного процесу, моделювання, орграф

Рассмотрена с одной стороны переменная система электроснабжения, а с другой – нестабильная система электроснабжения. В равновесие системы могут привести лишь процессы, в них протекающие под действием взаимосвязанных внешних и внутренних факторов. Использованы сети Петри и теория графов. Установлено, что вначале формируются основные факторы, которые определяют эффективность систем электроснабжения, далее с помощью орграфа строится модель процессов и выполняется оптимизация. Полученные результаты оптимизации важны при проектировании и эксплуатации электроэнергетических сетей, способствуют уменьшению энергетических потерь

Ключевые слова: электроэнергетические сети, эффективность, электропотребление, электроснабжение, факторы энергетического процесса, моделирование, орграф

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PERFORMANCE EFFICIENCY ANALYSIS OF ELECTRIC POWER SUPPLY SYSTEMS

N. Grigorieva
Doctor of Technical Sciences, Professor
Department of Computer Besign Eools and Eechnology Engineering**
E-mail: vik_shabajkin@ukr.net

L. Dobrovolskaya
PhD, Professor,
Head of Department*
E-mail: lsobchuk@gmail.com

D. Sobchuk
PhD*
E-mail: sobdim@gmail.com

V. Shabaykovich
Doctor of Technical Sciences, Professor
Department of Automated Management Production Processes**
E-mail: vik_shabajkin@ukr.net

M. Romaniuk
PhD*
E-mail: nickrom86@gmail.com

*Department of Electricity Supply**
**Lutsk National Technical University
Lvivska str., 75, Lutsk, Ukraine, 43018

1. Introduction

The problem of improving quality of electric power supply systems (EPSS) and electric power consumption systems (EPCS) during our crisis and unstable time is quite important due to the continuity and variability of technological processes of production and consumption of electricity. As you know, contemporary economy of Ukraine is characterized by a deformed structure of production, caused by power-intensive technologies, material-consuming products, excessive power consumption by the population, failures of old equipment, etc. The impact of factors differs by specific weight and by power consumption per hour.

The relevance of present work is in the increasing of efficiency of EPSS and EPCS by establishing factors of influence and optimizing the processes using directed graphs, which describe them. A minimum path corresponds to the reduction in power losses and cost of production and consumption, while the maximum path corresponds to the power efficiency of systems.

Thus, on the one hand, there exists an EPS variable, and on the other hand, the ECS variable; they can be balanced only by their optimization, which must be constantly operating. Such problem of uncertainty is global.

2. Literature review and problem statement

Paper [1] presents numerical analysis of sensitivity by critical parameters, such as technological costs and privileged tariffs. However, it does not address the specifics of power processes in electric power supply (EPS) and electric power consumption (EPC). Article [2] considers linguistic approach to the simulation of electrical systems, which allows increasing accuracy in determining the length of lines of different voltage, without losing their interpretation to the highest level. The disadvantage of the given study is that it considers general information on electricity supply systems without giving their details. In paper [3], the main classes of Petri nets and their application in engineering systems are shown. Specific features of the application of Petri net without linking to power networks are considered. In article [4], the systems methodologies of designing electrical systems, including the integrated optimal design with simulation and optimization methods, are considered. The issues of designing and optimization of electric power systems are considered generally and in fragments. Authors [5] try to develop a universal procedure to control the modes of power consumption using resource of technological process (TP) by constructing a conceptual model of energy consumption of generalized TP. At the same time, in paper [5], it is stated that the proposed methods cannot be applied in certain industries, as "this will cause deterioration of the qualitative characteristics of TP". Thus, the approaches, proposed in [5], are not universal enough. In article [6], an approach only to the construction of monitoring system of electric power quality in real time is presented. The work does not consider the interaction of main factors and their impact on improving the quality of electricity supply systems.

In paper [7], the research deals with the assessment of impact from generating sources of various power on the modes of electric power networks. However, the factors that affect efficiency of power supply were not established in the work.

Authors [8, 9] consider the issues of quality of power supply, but only combined with the dispersed sources of electricity. The proposed method and algorithms created prerequisites for software realization to evaluate reliability of local electric power networks only. The authors pay little attention to the solution of urgent tasks to improve efficiency of power supply of enterprises, no approach to optimize efficiency of the EPS and EPC processes was proposed.

At this particular level it is necessary to solve a number of problematic issues on efficiency of functioning of electricity supply systems, which require development of appropriate theoretical and methodological provision of quality. We speak here about formation of the main factors that determine the processes of improving efficiency in electricity supply systems, construction of models of these processes and their optimization. Solving a twofold task of EPS and EPC in this way will enable businesses to make products with innovative content that will be competitive in the international and domestic markets.

3. The aim and tasks of the study

The aim of present work is to increase effectiveness in electric power networks by identifying input factors of power processes, to model an impact of these factors and subsequent optimization by the criteria of maximization of effectiveness in their work while minimizing the costs.

To achieve the set aim, the following scientific and scientific-applied tasks were to be solved:

– to define the features of power processes in EPS and EPC;

– to establish factors that affect efficiency of the processes and relationships between them;

– to develop a method for selecting the factors that affect operation efficiency of electricity supply systems;

– to propose an approach to the efficiency optimization of electric power processes.

In this case, the object of study is the performance efficiency of electricity supply systems, and the subject is the processes of improving effectiveness.

4. Materials and methods for examining effectiveness of systems of electric power supply and power consumption

4. 1. Effectiveness of EPSS and EPCS as the main indicator of quality of electric power supply systems

When considering joint operations of EPSS and EPCS systems by the criteria of maximizing effectiveness in their work and minimizing the costs, a general scheme of standard EPSS and EPSC was accepted appropriate for research [10]. Its general view is shown in Fig. 1.

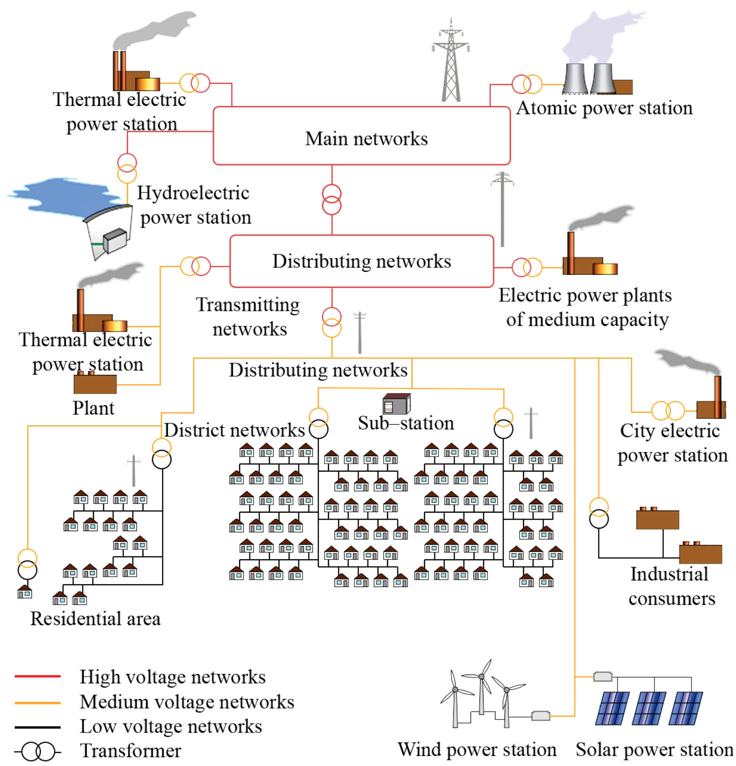

Fig. 1. Schematic of electric power supply systems in the European countries [10]

In the course of analysis, it was found that the shortcomings of such scheme for Ukraine include:

– physical and moral wear of equipment;

– low average technical level of the installed equipment;

– insufficient technical equipment and level of staff training in the operation of EPS and EPC;

– insufficient level of investment for technical re-equipment;

– low level of implementation of monitoring and diagnosis of conditions of equipment;

– imperfection of technology, diagnostic and repair works;

– outdated principles and methods for designing objects of EPSS and EPCS;

– insufficient loading of main lines, impermissible voltage increase and the decrease in network reliability;

– improper operation of EPSS and EPCS, which leads to considerable losses of electric power in electric networks;

– little compensation of reactive capacity in power networks;

– insufficient checking of networks under conditions of initiating powerful electro-receivers;

– insufficient testing and diagnosis of electric lines by different methods and other numerous shortcomings.

A non-uniformity in daily electric power consumption by large industrial enterprises leads to additional costs at peak hours of the day when the cost of electricity significantly increases. Thus, an enterprise faces the task of transferring electric power consumption from more expensive peak hours of the day to cheaper night hours by managing power consumption in order to minimize payment for consumed energy. It stimulates industrial enterprises to optimize the modes. Present research is aimed at the development of scientific basis of managing EPSS and EPCS, it is relevant and solves an important scientific task of improving power efficiency. The Ishikawa diagram [11] is used to examine the most significant cause-effect relationships between causes and consequences (Fig. 2).

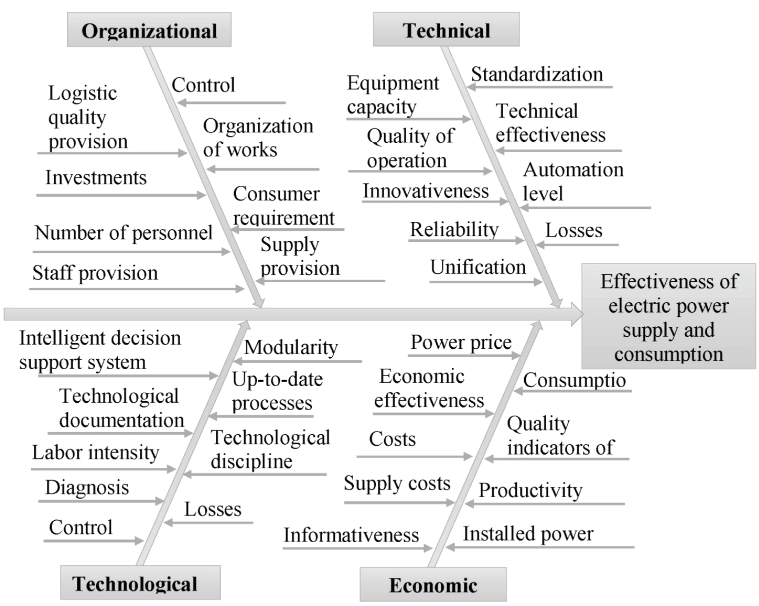

Fig. 2. Diagram of cause-effect relationships

The Ishikawa diagram is a graphical way for examining and determining. A group of organizational factors, which will determine effectiveness of the processes of EPSS and EPCS completely, ranks first. It includes technical preparation of production (TPP), all types of provision, investments, etc. The technical factors that make up the stem of the system, rank second, they include facilities and equipment, the level of automation, computerization, power capacity etc. They are followed by the technological factors that determine effectiveness of operation of the systems, and by economic factors, which express effectiveness through indicators of quality, cost and power price, general costs, etc. All listed factors are interconnected in various ways.

The resulting diagram is used as an analytical tool for examining the impact of existing factors and to isolate the most important ones. The action of factors causes specific effects.

4. 2. Simulation of electrical power processes

Simulation of such processes may be performed by different methods, one of which is the application of Petri nets [11]. Petri nets are an effective tool for discrete processes, in particular, the operation of energy systems. Such Petri net is a directed graph, the peaks of which are divided into positions and transitions. Formally, the net is represented as P (P, T, I, O, M), where P and T are the finite sets of positions; I and O are the functions of following and preceding, respectively; M is the initial marking. Designations control the net operation. The transition is excited by marking and works only when all the input positions of transition have designations.

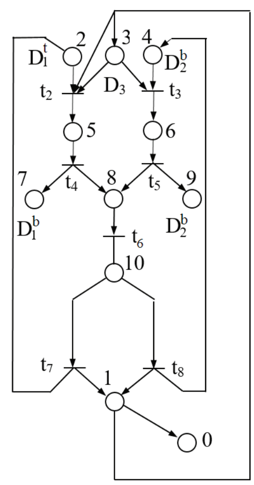

Fig. 3. Model of electric power processes by the Petri net

Fig. 3 shows the model to control electric power processes, which allows creating control in analytical form and is promising. The Petri net that models these processes consists of a simple net that reveals the features of energy generation, conversion, consumption and control. Positions 2–4 describe conditions of energy supply. Existence of markers in these positions corresponds to the operation of sensors D_1^t, D_2^b and D_3, and at transitions t_2 and t_3 the marker appears in positions 5 and 6 that describe the nets. After making the transitions t_4 and t_5 (starting additional equipment), markers are found in positions 7, 8 and 9, which correspond to the operation of sensors D_1^b, D_2^t. If a marker is found in position 8, transition t_6 is switched on and current supply to the network starts (position 10), transitions 7, 8 are responsible for emergency stops. Position 0 corresponds to the termination of electric power processes. In the presence of marker in position 1 (start of the next cycle) and in the correspondent positions that characterize the beginning of work, transition t_1, etc., is switched on.

The presented model is the basis for designing simulating electric power models of their individual functional nodes;

it uses the principles of modular and structural similarity. The principle of modularity lies in the fact that the object is divided into separate fragments, described by modular models. A general model is aggregated from constituents. Each module is technologically autonomous. The principle of structural similarity corresponds to the fact that a set of positions of Petri nets, its current layout, unambiguously describes technological state of the elements.

Thus, the Petri electrical power network is presented by a set of finite non-empty multitude of positions (power states), finite non-empty multitude of transitions (power actions). These are the functions of input and output incidences and initial marking (network marking out). They are graphically represented by a two-part directed graph with two types of vertices and arcs that match the incidence of positions and transitions. The network transition, if it appears to be excited, starts operating when marked, and it is replaced with a new one. The end marking, at which none of the transitions can start operating, is used to describe the blocking subsystem. Any power position or transition is interpreted as the Petri net of a lower level.

Using the queuing theory [12], one can analyze the same electric power supply system in terms of determining a probability of the number of requests, the average number of requests that are in the queue, the average waiting time of requests in the queue or in the system. For example, determining a shut-down in servicing p_o is performed as follows

$$p_o=\left(1+\sum_{n=1}^{m}\frac{m!\rho^n}{(m-n)!}\right)^{-1}, \qquad (1)$$

where n is the number of requests, received by the system; m is the maximum number of requests; p is the probability of receiving requests; ρ is the coefficient of using the system or downloading $\rho=\lambda/\mu$, λ is the failure intensity.

Thus, when forming a set of features for power systems, it is sufficient to construct appropriate graphs of the Petri nets. It is possible to explore by them the limitations and provision of operation stability, to identify a set of structural parameters. In this case, only parameters, which determine the optimum-stable functioning of a power system, are restricted by the analysis.

4. 3. Optimization of electric power processes in electric power supply systems

The EPS and EPC processes may provide high efficiency at the lowest possible costs. It is known that such non-optimum processes are ineffective and associated with increased production costs. To provide optimality, different methods are used. This problem is best solved by methods of multi-parameter synthesis [12]. This method is based on an analysis of elements and a system in general, on the method of generating options with the use of innovative approach and purpose-oriented search for optimal solutions without complete consideration of all possible options. In general, tasks of defining optimal variants of EPC and EPS processes are reduced to definition of characteristics of distributive function P (x), strategy C (y) and modes (y_x, u_x) in terms of minimizing performance indicator

$$E(X,C,y_x,u_x,P)=\min E(X,C,y_x,u_x,P) \qquad (2)$$

at $C\in Y;\ P\in\left(\overline{1,m}\right),\ m=1;\ X\in d\ (y_y(x));\ y_x\in Y(y_p(X))$.

Outer set X describes the diversity of purposes of power processes, which are to be covered by areas of feasible values d (y_i) of elements y_i in strategy $C(y_i)$. Multi-element strategy $C(y_i),\ i=\left(\overline{1,m}\right)$ allows taking into account the effect of some elements y_i, aimed at enhancing effectiveness of implementing set X and distributed between the individual elements. The most difficult task will be to get the area of specialization of strategy elements, which is a subset of areas of practically feasible parameters. Such a model can be described by the coupling equations respective to one dependent and two independent systems of inequalities that describe attainable set Y, it contains conditions of their realization and characteristics at minimal interval of power processes.

The optimization of distribution assigns function P(x). This function separates the area of specialization of each element of the strategy on set X. This multi-purpose approach provides qualitatively better optimal power solutions

$$E\ (X, Y, y_x, u_x)=\min E\ (X, Y, y_x, u_x), \qquad (3)$$

at $У\in y_x$, $y_x\in y(y)$, $u_x\in u(y)$, where X is one element of space of parameters, set requirements, such as costs of EPC and EPS; $X=\left(\overline{x_1,x_n}\right),\ Y=\left(\overline{y_1,y_n}\right)$ are parameters; У is regulation parameters. If X describes primary costs, parameters of regulation describe efficiency, reliability, and other indicators of quality of power processes.

A complexity of practical solutions of problems involving optimization of power processes is in the following. To determine their optimal parameters, it is necessary to consider and formalize certain modes, which are set from permissible subsets and depend on many factors. That is why this problem may be significantly simplified by dividing it into separate subtasks. It will somewhat decrease the adequacy of the model. The ways of enhancing adequacy include establishing rational versatility, specialization, division of undetermined parameters into insufficiently studied and obtained from incomplete goal setting, consideration of power process, as multi-element system, etc.

The optimization of power processes of EPS and EPC greatly simplifies this task. For the optimization, it is possible to recommend using the directed search method [13]. This method allows generating the required number of rational variants of elements' structures in the very beginning under conditions of incomplete initial data.

A general scheme of optimization of power elements consists of a series of interconnected stages. The most important and responsible task is to work out the algorithm for constructing a tree of power solutions with their following optimization. Taking into account all the source data, we compile competitive schemes of structures of individual elements. After analysis and synthesis of obtained solutions, their basic scheme is established, which is specified and optimized by accepted criteria.

Optimum variant of the structure of EPS and EPC is determined using the algorithm, during implementation of which a symbolic matrix, which points out the best options, is built. Such determining of the optimal structure may be performed by the Danzing algorithm, which is reduced to building an acyclic oriented tree [13].

After obtaining optimized variants of such elements, the achieved effect is compared to required costs. In general, the models of power efficiency criteria of the elements are reduced to form F=f (X, Y), where F is the efficiency criterion; X, Y are, respectively, insufficiently defined and known magnitudes; f is the objective function.

A choice of technological solution is reduced to the problem of optimization of functions on the admissible set of parameters at a fixed value of vector X. In this case, we take into account uncertainty, that is, inaccuracy of source data, characteristics, etc. This leads to the structure of an element with several performance indicators. Some optimal variants of elements may be obtained, and the difficulty in getting every decision is caused by the controversy of performance criteria. Then the task of optimizing individual elements will involve choosing their structure, optimal in terms of minimization of effectiveness vector. It is easier to establish the optimal structure both of the whole system and of a certain power element with the use of graph theory [14]. To do this, it is necessary to build a directed graph of EPSS and EPCS structures that displays a combination of the main and auxiliary elements (Fig. 4).

In Fig. 4, vertices of directed graphs show elements (energy generation, conversion and accumulation, consumption and control), and arcs show relationships between them (processes taking place in the EPC and EPS systems and between them).

The first and last vertices correspond to the start and the end of the structure selection. Possible structures depending on specific conditions of EPS and EPC may start at different vertices and include a different number of individual elements of the given sequence. The weight of the arc is determined by the time of performing functions of an element or its costs. Such directed graph describes both simple sequential structures, and more complex ones. In the beginning, the directed graph of the whole EPS and EPC system is formed, according to which their optimal composition and high efficiency (parametrical and functional optimization) are determined, and then constituent components are optimized using the same procedure. If necessary, it is possible to return to the previous stage – definition of the final state of EPSS and EPCS.

In a general case, such directed graph may be described by a system of matrix equations

$$\begin{vmatrix} t_{11} & t_{12} & t_{13} & \dots & t_{1,15} \\ t_{21} & t_{22} & t_{23} & \dots & t_{2,15} \\ . & . & . & \dots & . \\ t_{15,1} & t_{15,2} & t_{15,3} & \dots & t_{15,15} \end{vmatrix} \times \begin{vmatrix} \Pi \\ t_1 \\ t_2 \\ \vdots \\ K \end{vmatrix} = 0, \quad (4)$$

where t_i is the set of variables, which corresponds to a formalized element; t_{ij} is the time of performing the functions of certain elements, which corresponds to coefficient of transmission $d_{ij}def=t_i/t_j$. Solution to such equation is found by the known formulas [14].

The procedure for determining the optimal structure of the power process is as follows:

– necessary time of distribution of EPS and EPC structure is established by actual capacity;

– competing variants of electric power supply structures are considered by the chosen algorithm;

– competitive options are established, which are compared in terms of predicted costs of their implementation or other applicable criteria.

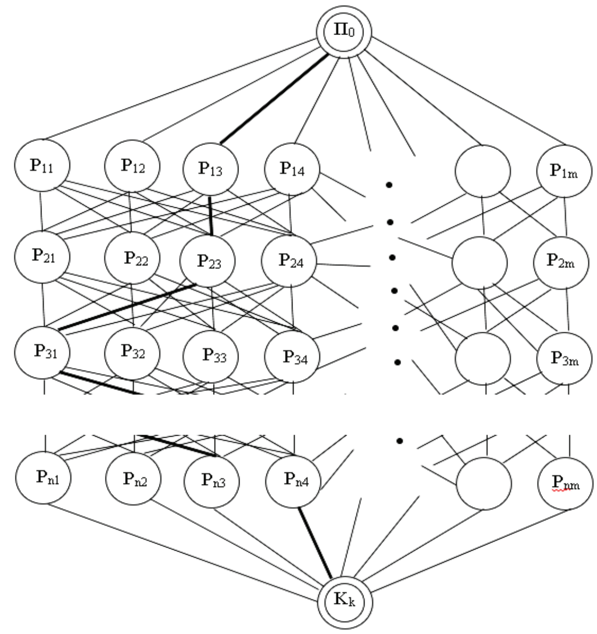

Fig. 4. Directed graph for selecting optimal solutions when designing EPSS and EPCS

Structural implementation of the optimal structure is associated with specifying structural characteristics. When establishing structural power configurations, we should take into account such indicators of quality as costs, reliability, etc.

According to the indicated indicators, the operation area of structural configurations will be uneven and may be described with a gradient of area

$$M(0)=\begin{vmatrix} M[grad_1K_1] & \dots & M[grad_1K_x] \\ M[grad_2K_1] & \dots & M[grad_2K_x] \\ . & \dots & . \\ M[grad_yK_1] & \dots & M[grad_yK_x] \end{vmatrix}=$$

$$=\begin{vmatrix} M[grad_{11}K_{11}] & \dots & M[grad_{11}K_{x1}] \\ M[grad_{21}K_{21}] & \dots & M[grad_{21}K_{x1}] \\ . & \dots & . \\ M[grad_{y1}K_{x1}] & \dots & M[grad_{y1}K_{x1}] \end{vmatrix}, \quad (5)$$

where $M[grad_jK_i]$ is the mathematical expectation of gradients, defined by formula

$$M[grad_jK_i]=\int_x\int_y\int_z \left|\frac{\partial K_i(X,Y,Z)}{\partial j}\right| \phi(X,Y,Z)dx,dy,dz, \quad (6)$$

where i is the coordinate direction; j is the gradient coordinate; x, y, z is the probability density; X, Y, Z are the coordinates of the operation zone of configuration.

By setting boundary magnitudes of mathematical expectation of gradients, it is possible to proceed to the identity-null matrix of limitations of these quality indicators. Properly conducted optimization of the structure of individual elements, their parameters and modes of operation of EPSS and EPCS include a series of stages, completion of which are the key to success.

A provision of the optimal solution is achieved by the application of different methods. Mathematical definition of characteristics of distribution function, strategy and modes in terms of maximizing performance indicator are required. In this case, the outer set of parameters describes the diversity of purposes of power equipment that is to be covered by areas of attainable values of elements of the strategy. Multi-element strategy allows taking into account the effect of several elements, aimed at improving efficiency of satisfying a set of parameters, which are distributed between individual elements.

5. Results of research into improving the efficiency of electric power supply systems

Automation of power facilities is an effective method of increasing efficiency of both EPSS and EPCS, and their optimization, as well as one of the most significant trends in the development of distribution complex. An important task for all complexes of the network is to create fully fledged automatic substations without attending personnel, integrated into a unified system of operational-dispatching control. At the objects, it is supposed to use automated system of power control and record, the system of power supply control, relay protection and automation, monitoring of electrical power equipment, registration of emergency situations etc. Integration makes it possible to optimize total costs of the system due to the combined use of various resources such as network devices, display tools, subsystem of single time, etc., as well as to increase profitability and faultless operation of the equipment due to a separate controlling interface per one working place.

The most difficult task is to receive the area of specialization of elements of the strategy, which is a subset of the area of technically feasible options. When setting the optimal configuration of power equipment and its elements, intelligent decision support systems under conditions of incomplete, inaccurate and sometimes controversial information may be of considerable importance. Generally, this information is difficult to formalize and the criteria are differently defined. The solution of such problems is carried out on the basis of the unstructured procedures, using expertise, qualification and intuition of designers.

Intelligent support includes analysis and synthesis of necessary information, methods of identification of building fuzzy systems, generation of its fuzzy databases using artificial means, such as neural networks, methods and algorithms of supporting different kinds of power decisions, interactive algorithm of solving multi-criteria optimization problems using, for example, genetic algorithms, development of application package of implementing intelligent decisions support systems, etc.

Intensive work in this direction is being carried out now, so a specific forecast may be complicated. In addition, intelligent power decision support system is intended to provide the optimal condition of the entire system relative to the selected criterion, regardless of its original state and previously made original decision. Thus, the procedure of establishing optimal configurations of power equipment may be seen in a wide and narrow aspects. The narrow aspect implies setting configurations, and the wide aspect also includes the structure, namely power equipment and its elements, which best demonstrate the result. The developed procedure includes a number of stages and phases, distributed between them. In this case, the most important points are formalization of power data, identifying the ways of EPSS and EPCS and forming a model of an ideal solution, establishing individual elements, their configurations, studying the operation of power equipment and its elements, and updating accepted decisions. The proposed way of describing modules and configurations presents them to the fullest, providing their description in detail, subsequently, when further processed, they may be brought even to schematic-numerical values.

6. Discussion of results of analyzing effectiveness in the operation of electric power supply systems

With an increase in certain quality indicators, in particular efficiency of electric power supply systems by optimizing energy processes, on the basis of the obtained results it can be argued that it is expedient to identify the main factors in these processes, especially the influence in their interrelations. In this case, it is necessary to distinguish their action according to defined effects. Obviously, it is due to this mechanism of factors' influence that the quality of operation of electric power supply systems may be enhanced. But at the same time, this mechanism has a negative impact on the optimization of the system because the optimization criterion is not satisfied, and therefore comes down to a simple group of elements of the systems, which significantly reduces efficiency of power systems. In addition, it is necessary to take into account mutual influence of individual quality indicators. Therefore, optimization can be considered important, namely, as a way of establishing necessary optimal elements after their functional and parametric improvement, which is not always successful.

The achievement of present studies is a comprehensive consideration of interaction between the main factors and their impact on quality improvement, based on which it is quite easy to perform modeling and optimization of electric power processes with the use of directed graphs. The lack of database on necessary indicators of operation quality of power systems, which would make the development more focused, may be referred to as a shortcoming.

To achieve the efficient technical solution, it is necessary to use preliminary simulating objects. And it is better to use the Petri nets, which is a simple and effective tool to study the operation of power systems. The developed Petri net is formed by four interconnected simpler systems that reveal the features of EPC and EPS processes. This gives the possibility to analyze and identify the data, necessary for systems as a whole and their elements in particular.

There are a lot of methods for functional and parametric optimization, but using the graphs of power systems and their elements is the most expedient. In the course of optimization of the system, vertices of the directed graph correspond to certain equipment and facilities, which is produced as standard, and the elements correspond to its components that are possible to develop and use. Then the task is reduced to searching the shortest (number of elements, costs, losses, etc.) and the longest paths (capacity, efficiency, etc.) in these graphs. A lot is being done in this direction, but even more needs to be done. Most of the questions are associated with situation variability in processes, insufficient and out-dated equipment, facilities failure, and low qualified staff, especially operational.

Conducted studies are extremely useful and could be used when designing and especially operating electric power supply systems. The continuation of the relevant research into synthesis of individual quality indicators of electro power supply networks in the future would be very appropriate as it would allow further expansion of the idea of internal features of the electric power processes and a significant increase in their quality. Continuation of work is planned for the future.

7. Conclusions

As a result of the conducted studies, it was established that:

– characteristics of electric power supply systems include variability of these systems due to power consuming technologies, unstable supply and consumption, and outdated organization of work;

– the factors, which influence such quality indicator as effectiveness of operation of electric power supply systems, were established. A diagram of cause-effect relationships was developed, which highlighted key factors, and revealed their influence and interconnections. The categories of factors include organizational, technical, technological and economic, with 7, 8 factors in each of them, which provides optimum-stable operation of power system;

– to outline the impact of individual factors for improving efficiency of operation of electric power networks, it can be argued that it is essential to identify the influence of the main factors on these processes, especially in their interconnection and to eliminate secondary ones that do not essentially affect the processes;

– it is more appropriate to perform modeling of EPS and EPC processes using the Petri nets, which are an effective tool for studying the functionality of electric power systems. The resulting Petri net consists of four interconnected, simpler systems that reveal features of energy generation, transformation and storage, consumption and control. These systems make it possible to analyze and determine likely number of shut-downs for maintenance, the average number of requests that are in the queue, the average waiting time of requests in the queue.

The studies are of great importance for the operation and development of electric power systems. The most effective optimization, which allows establishment of the optimal structure of EPS and EPC, is the use of descriptive directed graphs, the vertices of which correspond to the elements of the structure, and arcs correspond to the relations between them.

References

1. Khalilpour, R. Leaving the grid: An ambition or a real choice? [Text] / R. Khalilpour, A. Vassallo // Energy Policy. – 2015. – Vol. 82. – P. 207–221. doi: 10.1016/j.enpol.2015.03.005
2. Cordon, O. A proposal for improving the accuracy of linguistic modeling [Text] / O. Cordon, F. Herrera // IEEE Transactions on Fuzzy Systems. – 2000. – Vol. 8, Issue 3. – P. 335–344. doi: 10.1109/91.855921
3. Staines, A. S. Supporting Requirements Engineering with Different Petri Net Classes [Text] / A. S. Staines // International journal of computers. – 2010. – Vol. 4, Issue 4. – P. 215–222.
4. Integrated Design by Optimization of Electrical Energy Systems [Text] / X. Roboam (Ed.). – Wiley, 2012. – 320 p. doi: 10.1002/9781118561812
5. Rozen, V. P. Vykorystannja vnutrishnih rezerviv tehnologichnyh procesiv pry keruvanni rezhymamy elektrospozhyvannja promyslovyh pidpryjemstv [Text] / V. P. Rozen, M. V. Prokopec' // Avtomatyzacija vyrobnychyh procesiv: Vseukr. nauk. – tehn. zhurn. – 2006. – Issue 1 (22). – P. 26–30.
6. Volodars'kyj, Je. T. Monitoring system of electricity quality in decentralized electricity supply systems [Text] / Je. T. Volodars'kyj, A. V. Voloshko // Eastern-European Journal of Enterprise Technologies. – 2014. – Vol. 3, Issue 8 (69). – P. 10–17. – doi: 10.15587/1729-4061.2014.24890
7. Prahovnik, A. V. Perspektivy i puti razvitija raspredelennoj generacii v Ukraine [Text] / A. V. Prahovnik, V. A. Popov, E. S. Jarmoljuk et. al. // Energetyka: ekonomika, tehnologii', ekologija. – 2012. – Issue 2. – P. 7–14.
8. Sobczuk, D. Algorithmic realization impacts assessment for renewable sources electric power on reliability electrical networks [Text] / D. Sobczuk // Informatics, Control, Measurement in Economy and Environment Protection. – 2015. – Vol. 5, Issue 1. – P. 93–100. doi: 10.5604/20830157.1148056
9. Lezhniuk, P. D. Method for determination of optimal installed capacity of renewable sources of energy by the criterion of minimum losses of active power in distribution system [Text] / P. D. Lezhniuk, V. A. Komar, D. S. Sobchuk // Energy and Power Engineering. – 2014. – Vol. 06, Issue 03. – P. 37–46. doi: 10.4236/epe.2014.63005
10. Meier, A. V. Jump up [Text] / A. V. Meier // Electrical Engineer 137A: Electric Power Systems. Lecture 2: Introduction to Electric Power Systems. – 2013.
11. Casillas, J. Genetic tuning of fuzzy rule deep structures preserving interpretability and its interaction with fuzzy rule set reduction [Text] / J. Casillas, O. Cordon, M.J. del Jesus, F. Herrera // IEEE Transactions on Fuzzy Systems. – 2005. – Vol. 13, Issue 1. – P. 13–29. doi: 10.1109/tfuzz.2004.839670
12. Tasic, D. S. Modified Fuzzy Clustering Method for Energy Loss Calculations in Low Voltage Distribution Networks [Text] / D. S. Tasic, M. S. Stojanovic // Electroncs and electrical engineering. – 2006. – Issue 2. – P. 50–55.
13. Tasic, D. S. Fuzzy Approaches to Distribution Energy Losses Calculation [Text] / D. S. Tasic, M. Stojanovic // Acta Electrotechnica et Informatica. – 2005. – Vol. 5, Issue 2. – P. 29–35.
14. Haupt, R. L. Practical Genetic Algorithms [Text] / R. L. Haupt, S. E. Haupt. – John Wiley Sons, 2003. – 253 p. doi: 10.1002/0471671746