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Electric Power Supply Subsystem and its Role in Solving Production System Management and Planning Issues

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ABSTRACT

The relevance of the study is determined by the increasing role of prognostic models in the production system management and rising influence of the electric energy due to the high intensity of energy productions and growing price of the electric power. The objective of the work is to make provisions for the influence of electric power supply system on the process of planning and managing the production factors against time factor. The methods employed in the research are methods of wording and solving industrial engineering problems as the optimal control ones; algorithms and methods based on constraint equations. The paper discusses the questions of building the prognostic models for control and planning problems in production systems with time factors taken into account. As a result of the research it has been demonstrated that the influence of various factors on production system management processes can be perceived in an integrated way and the industrial electrical system has a sizeable effect on the production process. The importance of the study is demonstrated by finding the possibility to solve the control and planning problems with the integral influence of subsystems of the production system using industrial electric power supply system as an example. This allows enhancing the coherence of managerial decisions being made.

Keywords: Operation Research, Simulation Model, Production System, Electric Power Supply System, Control Parameters, Decision-making Support
JEL Classifications: Q40, Q41, Q42

1. INTRODUCTİON

Although the economy development vector is oriented to the development of industry and commercial output, this does not guarantee the economic effect and successful implementation of projects. What is particular about introduction of new product projects is that in innovation projects introduction all or individual project implementation stages have the elements of novelty and uncertainty. These are going to depend on the certain project, which touches on all subsystems of the production system that implements such a project. It also makes it necessary to consider their features in an integrated way. It results in an interdisciplinary character of the process associated with control and production output and multi-factor nature of the introduction and output process. The time factor has to be taken into account due to this as well, as the modern products have an increasingly shorter commercial lifetime combined with the increased quantity of modifications and component parts of items.

Production systems that implement new products operate under uncertainty manifesting itself in various ways: While goals and sub-goals are determined, as random factors arise, with the lack of resources, and during the very production system functioning. In the system, it is the random factors that frequently are sources of uncertainty; moreover, they are interrelated and indirectly influence all parameters of the project-implementing production system.

When implementing the projects, production systems generate new needs and requests for manufacturing the items and for production capacities that are up to special requirements of the production systems. At the same time, it can be observed that introduction of any changes takes place in conditions of strictly limited time and budget. Frequently, it is the case that individual affiliate companies are created for introducing the new projects and developments or that projects being introduced are viewed as an independent one that shares resources or goals with other works.

Each project of this kind needs solutions available for control and planning problems proceeding from the existing resources, environmental factors and strategic plan of the PS development.

The above aspects taken together place an increased responsibility upon the person who makes decisions, because the risks (Mylnikov and Kuetz, 2017) associated with the innovation project implementation grow considerably, which means, so does the relevance of methods and approaches that allow enhancing the objectivity of decision-making in managing the commercial projects in production systems.

Single numerical evaluations and solutions play an ever smaller part in managing and making managerial decisions, while the importance of qualitative and integrated evaluations goes up. Due to higher volumes of the information accumulated, there began to arise problems of parameter monitoring and forecasting, creating the systems which trace back the dynamics of parameter change and parameter values matching the planned ones (Kaiser et al., 2011).

Meanwhile, there is a marked lack of methodological approaches to formalize the problems of project management in production systems, even though research has been conducted in the area for a long time. The methods of objective decision-making under limited time for solving control and planning problems face the NP-completeness problem, due to which many of them can only be solved using the approximate methods.

The development of Industry 4.0 and IIoT concepts, in particular, the possibilities of gathering information about each equipment unit and controlling the production processes in production systems online (Arnold et al., 2016), opens up new opportunities for the development of industrial engineering methods.

With regard to this, coming close to the performance targets is not a one-step process but it is a path of mutually dependent conditions. Moreover, the very performance targets change over time and can be a set of values connected by various relation types (Mia and Winata, 2014).

Thus, it becomes essential to view the control problems with time factor taken into account, and using the statistical data for that makes up a possible way for building forecasts and assessing the planning risks while also considering overall PS specific nature, the equipment used and organization of processes under limited time.

2. LITERATURE REVIEW

For a long time, methods of decision-making in conditions of limited data and using expert appraisal were developed. Among them, the following methods can be listed: The utility theory (user preferences are considered for maximizing the expected utility and probability models (Neumann and Morgenstern, 2007); the approach based on decision trees – its essence consists in decomposing a problem into a number of sub-problems (see works by H. Raiffa); multi-criteria utility theory (developed on the basis of works of R. Kenney)), prospect theory methods, Electre methods (developed by the French school of decision-making theory led by B. Roy), the analytic hierarchy method suggested by Saaty and Forman (1996), heuristic methods (e.g. the one of weighted sum of criteria evaluations, the compensation one etc.), bounded rationality models by A. Rubinstein, the technique for order of preference by similarity to ideal solution (Walczak and Rutkowska, 2017), models based on Markovian processes theory (Dimitrakos and Kyriakidis, 2008), the use of simplified production models and modeling of random deviations (Chelbi and Ait-Kadi, 2004).

The accumulation of a large volume of statistical data gave a new boost to the development of mathematic formalization methods for solving the problems of controlling the materials, sections (parts), operations, choice of suppliers (Aissaoui et al., 2007) and considering the stochastic factors in them. The probability approaches to risk assessment allowing for various characters of the events considered (joint, mutually dependent, disjoint and mutually dependent ones) came to be applied for solving the planning tasks subject to the dynamics of the processes under consideration.

The efficiency of management directly depends on the organization of processes and their interrelation in production systems. Process-based approach is characterized by evident actions, evident initial conditions and results. However, there are processes lasting for a long time and having no strictly determined description and end result (Handbuch Projektmanagement, 2011) (examples of the processes are learning, management etc.). In practice, well-formalized and automated production processes and ongoing management and business processes are distinguished (Gadatsch, 2012).

Thus, it can be concluded that processes are characterized by a set of certain tasks and transitions between them that both are fulfilled within the production system considered and may have connections with processes and tasks that are external toward the system. Importantly, the processes can only be changed by systems that control them and are their holders (Damij and Damij, 2014), which means, managerial decisions have to be taken at the corresponding levels. The necessity arises if the results expected from the PS fail to be achieved.

Unlike processes, a project is generally a one-time initiative that touches on many subsystems of the PS and focuses on certain goals (urgent, interdisciplinary, critical or especially important) that are unattainable in the formed managerial structure and require special control (Handbuch Projektmanagement, 2011), which renders each project unique. Moreover, projects can have changing end goals - this is especially true for innovation projects being implemented in a competitive market environment and are a priority for the PS (they are crucial for the existence of the PS and influence the speed of their development).

However, if commercial projects implemented in production systems are discussed, these are based on the operations management of a group of projects in conditions of the efficiency assessment processes already formed in the PS (Esfahanian et al., 2014) (they rely on the traditional hierarchy of indicators (e.g. DuPont model) and have only one target - profit, which is not sufficient in implementation of innovation commercial projects because management of such projects is based on a number of performances, sometimes controversial ones). There are also processes of introduction and control of new projects (Kerssens-van and Cooke, 1997) (with them, the multidimensionality of innovation projects can be provided for yet the development and profitability growth of the PS, nor the optimum character of decisions made are set as a goal); collection and analysis of input data, data about production processes, output data and production results (Brown and Svenson, 1998) (when the shared data for the system are collected, as a rule, data characterizing an individual project cannot be singled out); and the information infrastructure (Kütz, 2014). Nevertheless, all the said approaches do not provide for the stochastic character of parameters in decision-making models that can at the same time have various relationships. They can be joint, mutually dependent, disjoint and mutually dependent. Special methods have been developed for some relations of parameters and their values (e.g. the efficient overall optimization method based on Bayes theorem, see [Tajbakhsh et al., 2015]). The model ignore the time factor gaining an increasing importance, both in relation to direct planning and to stable operation of the system under consideration in its interaction with suppliers and partners, equipment operation and the products sale process (Gunasekaran and Ngai, 2012).

3. MATERİALS AND METHODS

3.1. The Method of Management Based on Performance İndicators

Management works with objects that can be managed. Management object is located in the state space. The management object parameters that are important for achieving the managerial problems act as coordinates of n - dimensional state space. Values of the parameters show how efficient the management object state is for achieving the set tasks.

Goals to be achieved are called the goal vector z_p, and the current state of the management object is described by vector z_a. The estimate d (z_a, z_p) is introduced as the distance between the target and current states of the management object in the state space considered. The management object state is the key performance indicator of management. If $z_p = z_a$, then the goal has been achieved and management has succeeded in its problem. Vector z in classical understanding is a performance chart, a list of indicators.

Practice shows that in management a manager has to know not only the management performance indicators pointing at the achievement of goals $(z_p = z_a)$. In order to work efficiently, a manager needs as much information as possible. A manager has to have at hand so-called data about the "weather" in the organization, the parameters that are unchangeable but important for managing various activities. Thus, n - dimensional state space is associated with the management object and provides this additional information. Here y_e is the vector of expected data about the "weather" in the organization and y_a is the vector of acute data about the "weather" in the organization. Solution of the managerial problem can be much more complicated when $y_e \neq y_a$ as compared to the case with the condition of $y_e = y_a$. In spite of this, managerial goals $(z_p = z_a)$ can be achieved even under the adverse external situation $(y_e \neq y_a)$.

For management to be efficient, the following problems have to be solved:

- The "correct" parameters for describing the management object and its relevant surrounding have to be determined;
- The parameter values have to be found that describe in the best way the set goals and the expected external situation to be borne in mind for achieving the goals;
- İt has to be checked that the relevant parameter values are measurable in the current or periodical modes (the process is called monitoring);
- Deviations have to be recorded and results have to be submitted to the management structure;
- The management structure has to be assisted in interpreting the results and making the "correct" decisions.

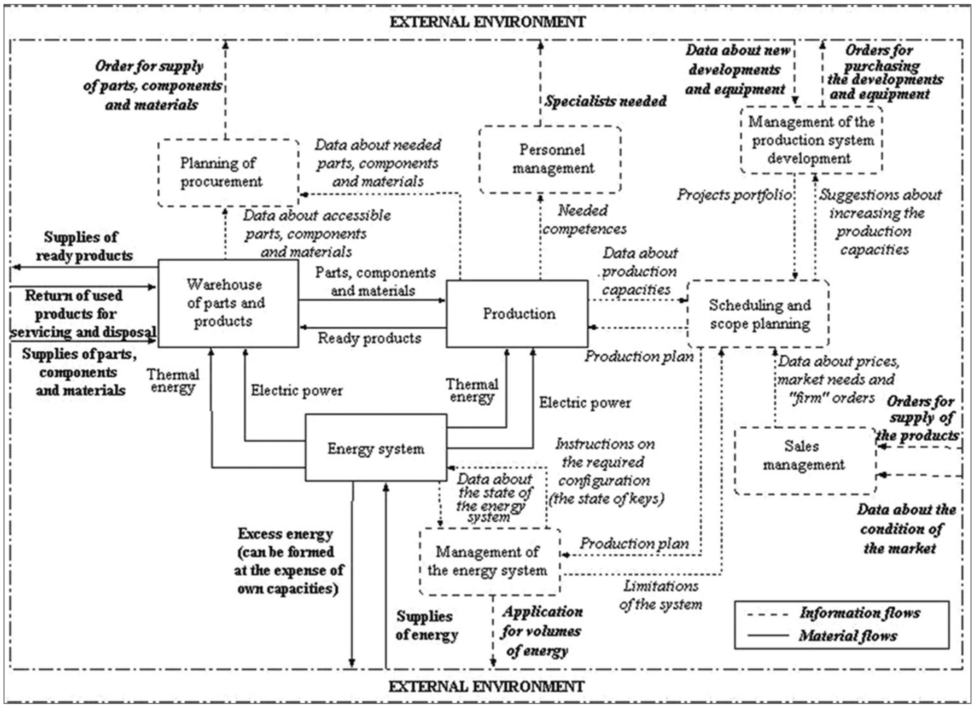
In large companies, managers who are responsible for management performance indicators are special experts performing this preliminary work. In smaller companies, each manager has to be independently responsible for management performance indicators. On balance, management performance indicators are a special aspect of management.

3.2. Description of Production System when Solving the Control Problems

The efficiency of functioning of a production system depends on the organization of processes taking place in it (Figure 1). Meanwhile, there are some external factors that are difficult to be influenced and that influence directly the system's functioning. These are not only the factors related to products output itself, but also the resources consumption control problems that depend on the market situation: Demand and price for the products manufactured, the volume of supply and cost of parts, components and materials, the supply and prices at the labor market, and the state-of-the-art developments and equipment market.

An increasingly greater contribution to the cost of the final products is made by the energy resources, by electric power used in the production system operation in particular. It is important to control this kind of energy due to stricter requirements for the quality of electric power, lower risks of power outage, and the higher energy intensity of production processes. This makes it essential to take energy-saving measures and to pay more and more attention to energy system management questions. Most control problems, such as controlling the procurement, sale, scheduling and scope planning, managing the energy system included, are solved individually. Due to this, the factors of their mutual influence are ignored. In some cases, when problems are worded as optimization ones, further constituents are introduced into the criteria in order to take into account the influence of more

Figure 1: Functional diagram of a production system



factors. However, if the work of electric power supply systems is considered, such approach does not allow providing for non-routine situations, production and planning risks.

This is why for assessing a situation or results models have to be given a "test run" (implementation, "rehearsal") but not "solved." In particular, various problems can be united within one model either by serial computation (the model is viewed as a directed graph, so the computational problem is brought down to that of traversing the directed graph (Aho et al., 1983) and performing the algorithms, methods and models of work with the data corresponding to the graph nodes) or by parallel calculation methods (Mylnikov, 2016).

Parallel calculations can be used if it is permitted to use the current input data for obtaining results in each block. In practice, this leads to delays in data being distributed and valid results being obtained from input to output, the delays depending on the quantity of series connected model blocks between its input and output. However, this approach allows paralleling the computational process without limitations and raise the speed of calculations. Unlike the previous ones, performing the parallel calculation has to use the mathematical tools based on matrix theory:

$$[F] = -([A][M]\,[A]^{T})^{-1}\,[A][M][E],$$

Where [φ] is the matrix of values of variables at the model blocks output, [A] is the matrix of incidence showing the interrelations between elements of the model. [M] is the matrix of values showing how much the input value variable of the model element is going to be adjusted, [E] is the matrix of additional actions and deviations (modeling the random influences of the external environment).

4. RESULTS AND DİSCUSSİON

4.1. Formalization of Electric Power Supply Subsystem Control Problem in Production Systems

The electric power supply system of an enterprise is created not at once but in an evolutionary way, as new consumers (productions), requirements for electric power supply systems etc. emerge. Hence there are possibilities for invariant connection of consumers and the use of equipment having various characteristics and supplied at different time for transmitting the electric power.

Several main approaches are used for describing the electric power supply system:

1. The joint solution of equations for all elements of the system (Bachovchin and Ilić, 2015; Poudel and Cecchi, 2017). Given the composite system in question, all differential equations cannot be united for being solved jointly within the set problem. Solving a system of equations of such order is inexpedient and practically impossible, even with the modern computers. Equivalenting does not eliminate the said problem, as the system remains composite anyway. This approach can be applied for studying the behavior of the simplest systems as well as for checking other algorithms using the cases of the simplest systems.
2. In order to calculate both established and transition modes in electrical systems, a model can be built on the basis of transmitting the reactions from some model blocks to others as actions (Esfahanian, 2014). However, here the connections direction selection problem arises as well as that of stability of the solution. A great advantage of this method is the simplicity of organization of interaction between blocks - there is no need to solve constraint equations.
3. Algorithms based on solving the constraint equations

(Kavalerov and Odin, 2017; Tarasov et al., 2016). There are various modifications and record forms of constraint equations solution algorithms, and selecting the best one of them is questionable.

4. The methods of diakoptics (Lui, 1998) make up an individual group of methods for studying the composite systems.

For considering the electric power supply problems jointly with other control problems in production systems, it makes sense to opt for the 3rd group of methods. The positive aspect in the matrix and topology based direction of the chain theory consists in highly ordered compiling of equation systems, compactness, and the possibility of solving high dimensionality problems, as well as in that of wording the problems for calculating the work modes which are optimum in this or that sense.

The mesh-current method and the nodal voltages one belong to the selected group. They allow easily monitoring the correctness of calculation, as the variables are given in them in the evident form and their values can be extracted at any time point. The nodal voltages method has an advantage over the mesh-current one only in the case when the quantity of equations written down under the first Kirchhoff's law is smaller than that of equations written down under the second Kirchhoff's law. If the set electric diagram has q nodes and p branches, then according to the above the nodal voltages method offers an advantage under $q-1<p-q+1$, or similarly for $2(q-1)<p$. In the actual electric power supply systems of production systems, the quantity of nodes is always smaller than that of branches, so it makes sense to build the elements interaction model on the basis of nodal voltages method - the latter is less cumbersome.

If the potential of the basis node is adopted as equal to zero, then the voltages between the remaining nodes and the basis node will be equal to the potential of these nodes (in this case the method is called the nodal potentials one).

The column matrix of branch voltages can be written down via the transposed matrix of incidence and the column matrix of potentials of the ungrounded nodes:

$$[U] = [A]^T[\varphi]$$

Here matrix [U] is the column matrix of voltages; [A] is the matrix of incidence; [φ] is the column matrix of potentials of the ungrounded nodes; [E] is the column matrix of EMF.

The constraint equation for the system based on the potentials method will take the form as follows:

$$[A][G]\,[A]^T\,[\varphi] = -[A][G][E]+[A][J]$$

Where [J] is the column matrix of current sources.

The goal of solving the constraint equations is to determine the potentials of nodes in electric power supply diagram. As a rule, it can be taken that the system has no current sources, so [J] = 0. Then the obtained formula for the potentials is:

$$[\varphi] = -([A][G]\,[A]^T)^{-1}\,[A][G][E]$$

Here the constraint equations are going to be modeled and solved in d, q coordinates system. In this algorithm, the matrices of incidence, conductivity and EMF are cellular. Cells of the incidence matrix have the size of 2 × 2 and they can be individual matrices or contain trigonometric functions. The cells of conductivity matrix are determined by the real and imaginary conductivity values:

$$G \rightarrow \begin{pmatrix} g_d & g_m \\ g_m & -g_d \end{pmatrix}$$

Where g_d is the real component of complex conductivity and g_m is the imaginary component of complex conductivity.

Similarly to the conductivity, the EMF column elements turn into columns containing the complex EMF:

$$E \rightarrow \begin{pmatrix} e_m \\ e_d \end{pmatrix}$$

Where e_d is the real component of complex EMF and e_m is the imaginary component of complex EMF.

Using the above formulas and Ohm law, the expression for the current can be put down as follows:

$$[I] = [G]([A]^T\,[\varphi]+[E])$$

Here matrix [I] is the matrix of currents running in the branches and [G] is the diagonal matrix of branches conductivity.

The production equipment and electrical equipment are characterized by consumed, delivered or transmitted power.

The expression for the active power will have the appearance:

$$[S] = ([A]^T\,[\varphi]+[E])[I]$$

Where matrix [S] is the matrix of powers of the branches.

Next, the powers running in all branches are to be determined:

$$[S] = ([A]^T\,[\varphi]+[E])^2\,[G]$$

Where [G] is the diagonal matrix of conductivities of the branches.

Thus, knowing the voltage of a higher node and the power running in the branch, the installed equipment can be checked according to the voltage and power or current, depending on the element type.

It is sufficient to view the stationary models as modes in which the electric power supply diagram exists for a long time are analyzed, and the search results are also the established modes of the kind. Hence it is not justified to view the quickly progressing transition processes. However, the dynamic model based on the potentials method can be built by introducing the calculation period Δt(t).

One of the main characteristics of an electric power supply diagram is voltage in buses. The criterion is selected because it is recommended to avoid slumps or excess voltages in buses: İn the case the equipment goes beyond the calculated parameters and its work modes are changed (Mylnikov, 2005):

$[\varphi]\rightarrow[\varphi_{nom}]$

Where $[\varphi]$ are potential in node points (in buses) and $[\varphi_{nom}]$ are rated potentials in buses.

Alongside with tending to rated values, the permissible spread of supply voltage are regulated, as a rule, in per cent:

$$\left[\varphi_{nom}\left(1-\frac{\Delta_1}{100}\right)\right]\leq[\varphi]\leq\left[\varphi_{nom}\left(1+\frac{\Delta_2}{100}\right)\right]$$

Where Δ_1 is the permissible voltage spread in per cent for the nodal point downwards and Δ_2 is the permissible voltage spread in per cent for the nodal point upwards.

It is worth paying attention to branches containing transformers. In literature, when modeling energy systems it is supposed that the current runs through transformers in one direction only (from the input winding to the output). However, the situation is theoretically possible when the current runs through the transformer in the reverse direction. In this case, the problem of relevance of the transformer model in this situation arises but this problem is not the system modeling one. So, this limitation can be ignored and only the following limitation can be used:

$0\leq[I]$

The next limitation follows from the fact that a power that is higher than the sources can produce or than one by which the consumer is limited cannot be obtained from the voltage sources:

[S]≤[S_eds]

Where [S] is power running in the branch having an EMF source and $[S_{eds}]$ is the power of the EMF source or the power by which the consumer is limited.

The possibility of supply loss for certain elements can be eliminated by placing 0, 1 and −1 in the relevant locations of the incidence matrix. Thus, a part of structure of the electric power supply diagram becomes determined.

Using the expressions given before, the problem will have its final appearance as follows:

$$-([A][G]\,[A]^{T})^{-1}\,[A][G][E]-[\varphi_{nom}]\rightarrow\min$$

$$[\varphi_{nom}(1-\frac{\Delta}{100})]\leq-([A][G][A]^{T})^{-1}[A][G][E]\leq[\varphi_{nom}(1+\frac{\Delta}{100})]$$

$$([A]^{T}\,[\varphi]+[E])^{2}\,[G]\leq[S_{eds}]$$

$$a_{ij}\in[0,1,-1];i,j=\overline{1,n}$$

Where n is the quantity of branches in the diagram.

It is the incidence matrix determining the system configuration which is the unknown in the problem.

After optimization under this model, the values of currents running in the branches can be changed due to the system configuration change. So a new calculation of protection set points can be required in order to avoid their abnormal operation.

However, if the solution has to be found within the existing protection set points and safety devices installed, this model has to be supplemented with limitations for branches where current protection operation elements are installed:

$-[I_{lim}]\leq[I]\leq[I_{lim}]$

Where $[I_{lim}]$ is the limit current which is permissible in the branch (the minimum protection operation current).

The electric power supply system control problem can be integrated with the production system control problem by means of their coupling via the production plan. For this, the production plan has to be turned into a list of the equipment and power consumed in the electric power supply system branches that are required for each time point. Then parameters [A] and $[S_{eds}]$ will depend on time [A] (t) and $[S_{eds}]$ (t).

The feedback between the planning problem in productions systems (Mylnikov, 2017a) and the electric power supply system control problem can be carried out by accounting the expenses for the use of electric power, in particular, ones for electric power use modes in different times of day and with various limit powers, as well as the size of payment for work in different times of day and in different days. Then the criterial function will be supplemented by constituents allowing for the expenses for the electric power as follows:

- To minimize the production expenses variable, it will be: $\Sigma_p(costeq_{pgj}(t)+\Sigma_m part_{mpgj}(t)price_{mi}(t)+\Sigma_m part_{mpgj}(t)ship_{mij}(t))$ $+powerprice(t,S)\,S(t)+workerprice(t)workercount(t)\rightarrow\min$, $\forall g, j$,
- To maximize profit (planning of production for the demand), $(sell_n(t)-\sum_j cost_{jn}\,(t)-powerprice(t,S)S(t)+workerprice(t)$ $worcercount(t))\sum_j y_{jn}\,(t)\rightarrow\max$, $\forall n$,
- etc.

In particular, the problem will also be supplemented by the required limitations against time factor:

- Branch power limitation $([A](t)^{T}\,[\varphi]+[E](t))^{2}\,[G]\leq[S_{eds}](t)$;
- Limitations for branches where current protection elements are installed $-[I_{lim}]\leq[I](t)\leq[I_{lim}]$;
- Production capacities limitation, $\sum_g eq_{pgj}\,(t)\leq supmaxeq_{jp}$ $(t),\forall j,p,t$; 0
- Limitation in the opportunities of components and materials supply, $\sum_g part_{mpgj}\,(t)\leq supmaxpart_{jm}\,(t),\forall j,p,m,t$;
- The requirement of non-negativity for the volumes of products, orders and the like, $y_{jn}\,(t),x_{ijm}\,(t),r_n\,(t),o_m\,(t),d_m\,(t),ref_{jm}$ $(t)\geq 0,\forall j,n,i,m,t$;
- Demand volume limitation, $\sum_j y_{jn}\,(t)\leq dem_n\,(t),\forall n,t$;

- Description of particularities of the production process, $\sum_n req_{mn}\ y_{jn}\ (t)=\sum_i\ x_{ijm}\ (t)+ref_{jm}\ (t),\forall j,m,t,\ \sum_j\ ref_{jm}\ (t)+d_m\ (t)=o_m,\forall m,t,\ o_m\ (t)=\sum_n\ req_{mn}\ (t)r_n\ (t),\forall m,t$;
- Order scope limitations, $\sum_j\ x_{ijm}\ (t)\le supmax_{im}\ (t)\ s_i\ (t),\forall i,m,t,\ \sum_j\ x_{ijm}\ (t)\ge supmin_{im}\ (t)\ s_i\ (t),\forall i,m,t$;
- And so on.

In the notation (Moghaddam, 2015) $costeq_{pgj}$ is the price of performing operation p with equipment g in PS j; $part_{mpgj}$ is the need of parts/materials m for performing operation p with equipment g in PS j; $price_{im}$ is the price of part m obtained from supplier i $ship_{m/nij}$ is the price of delivery of part/item m/n from destination i to destination j; powerprice(t,S) is the price of electric power depending on the time and power consumed S; workerprice(t) is the price of man-hour depending on the time of work and workercount(t) is the quantity of man-hours required for performance of works. i is the index of supplier; j is the index of production system/warehouse (PS). m is the index of part or need of material; n is the index of the end item and k is the index of production operation. g is the machine or tool index; p is the index of the operation; t stands for time. x_{ijm} is the quantity of parts m obtained from supplier i for PS j;y_{jn} is the quantity of items n produced in PS j;$_{rn}$ is the quantity of items n returned for disposal; o_m is the quantity of reusable parts or materials m and d_m is the quantity of parts or materials m directed for disposal. $sell_n$ is the selling price of item n;$cost_{jn}$ is the production price of item n in PSj;$dem_{(j)n}$ is the need/demand for item n, if there is index j this means with consumer j;req_{mn} is the quantity of required parts m that are necessary for producing item n,eq_{pgj} is the need of equipment g for performing operation p in PS j;$supmax_{im}$ is the maximum size of the lot of parts m that can be supplied by supplier i;$supmin_{im}$ is the minimum size of the lot of parts m that can be supplied by supplier i;$supmaxpart_{jm}$ is the maximum possible quantity of parts and components m that can be supplied for production in PS j and $supmaxeq_{jp}$ is the maximum possible quantity of equipment units for operation p in PS j.

A new factor considered changes the organization principle of calculations and modeling possible states in the production systems.

The time factor considered when solving the problems worded as optimization problems brings some particularities into the method of solving the problems because it is not only the solution that becomes a function of time but also the functions and criteria prove to have limitations. The obtained problems belong to the class of multi-parameter problems with nonlinear limitations. As there are currently no analytical methods for solving the resulting problems, the solution for this problem will be built on the repeated cyclical finding of numerical solutions for the multi-parameter optimization problem with time span which determines the precision of description of the function sought for.

The modern methods are conventionally subdivided into three groups (Burke et al., 2003): Cluster methods; limitations distribution methods; and meta-heuristic ones. When choosing a solution method, it should be remembered that the most important property of combinatory optimization methods is their completeness. A complete method guarantees finding the solution for the problem in case one exists. However, the application of these methods can be difficult with the large search space dimensionality, and the quantity of time which may be required for search can turn out to be unacceptable (e.g. if there is limited time to make the decision). If heuristic methods are used in solving the problem or elements of heuristics supplement the combinatory methods, then it is more complicated to prove the completeness of the method employed. Heuristic search methods are mainly incomplete.

In practice, hybrid algorithms are frequently applied. Moreover, the results of work of an algorithm can often be improved by constructing a cooperative solver. For the formalization obtained, due to the lack of specialized solution methods, it can be considered justified to use the evolutionary approach - the stochastic search method. The disadvantage of evolutionary approaches is the dependence of results and optimization time on the selection of initial approximation in some cases. The disadvantage can be leveled out by using a solution developed by experts as the initial approximation. This is why the stochastic search method with expert knowledge and fuzzy preferences is going to be used here as the universal one. However, with regard to this it should be borne in mind that for some problems formalizations can be obtained for which there are solution methods. In such cases, the decision on applying this or that method should be made depending on the exactness of the solution required and on any time limitations concerning the search of solution (time limits are possible for stochastic search methods, which is especially important in inbuilt systems and the IoT working in real time).

Among the heuristic methods of random search, two large groups can be singled out: The random search methods with learning and the evolutionary programming (Syswerda, 1989). The practical application of the methods differ in speed, convergence and the quantity of iterations required for finding the permissible solution (some methods, such as genetic algorithms, guarantee finding an extreme solution but not necessarily the optimum one). The complexity of selection problem is also due to the efficiency of some stochastic search methods (GA in particular) being determined by their parameters.

As an example for solving the problem, the application of the random search method with prohibitions (Pareto simulated annealing) (Jaszkiewicz, 2002) will be considered. It is supplemented up to the modified problem for working with limitations set by values that were obtained as a result of forecasting. In order to start the numerical solution, the region has to be determined within which the acceptable solutions will be located. The algorithm is going to have five steps and the additional sixth step to allow for solving the problems with limitations set by functions and forecast values, as well as with the given precision and criterion in which the values obtained in forecasting can also be used.

Let the variant of searching for parameter values $x_i, i=\overline{1,N}$ as points in space B_i be considered. Λ^{**} stands for the set of all points x_i satisfying the limitations of the problem: $\Lambda^{**}=\{x_i^{(j)}\in B_i^{(j)}, j=\overline{1,N^{**}}\}$ (included into the acceptable values region), where N** is the power of finite set $B^{(N)}$, and N is the quantity of components in the vector of the unknown. So the algorithm is reduced to the following sequence of steps:

1. Setting N** - the required quantity of points from set Λ^{**} (N** is the parameter of the algorithm). Depending on the certain problem, value of N** can change;
2. Finding N** points for each parameter $x_i \in \Lambda^{**}$ scattered in spaces $B_i^{(N)}$ randomly or using the expert knowledge and using the points as the initial approximation;
3. Using one of the heuristic methods of stochastic search to find solutions $x_i \in \Lambda_{D_i}$ (Λ_{D_i} is the set of acceptable points). For this, point $x_i \in \Lambda^{**}$ is taken as the basis and new points belonging to Λ^{**} are constructed in which the criterion values are better than in the basis point. If at least one such point has been found, it is used for finding new values again, and in this way further search is conducted. All points $x_i \in \Lambda^{**}$ thus found will make up set Λ_{D_i};
4. All points $x_i \in \Lambda_{D_i}$ are studied for optimality, with optimum solutions set Λ_p to be formed of them. Using the patterns, the sought for sets are easily restored in the criteria space;
5. Selecting the only variant of $\hat{X}$, where X is vector $\hat{X} = (x_1, x_2, ...x_N)$, from pareto set is given to an expert having further information that cannot be formalized and is not provided for in the model;
6. In order to promptly response to the changing external factors, the problem has to be solved repeatedly (modeling the deviations of forecast values within the trusted range) and cyclically with time span Δt.

As a result of the solution, the changing over time range (corridor) of possible solutions for each time point is obtained. Meanwhile, as some functions describe parameters set with the help of forecasts the precision of which depends on the planning horizon, there may be a situation when the values obtained oscillate upwards or downwards. Such dynamics will yield further organizational costs for production systems; however, the behavior can be controlled (the values change can be reduced to smooth adjustment) at the expense of changing the variables within the corridors obtained and time increment Δt.

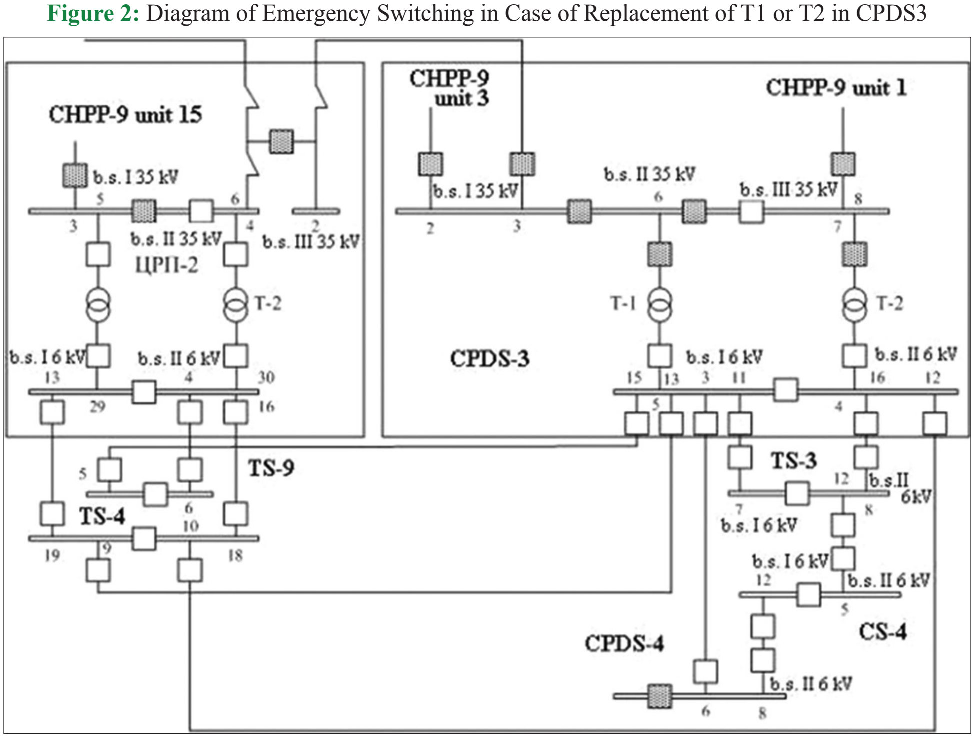
As a result of the solution, the ranges and values of variables are determined that can further on be presented in a way that is convenient for the decision-making person (e.g. as a Gantt diagram that is fairly popular in management) (Gantt and Forrer, 2006).

4.2. Solutions Obtained when Considering the Electric Power Supply Subsystem

In order to study the efficiency of allowing for work modes of the electric power supply diagram, the work modes of emergency connection diagram are discussed using the case of an industrial enterprise (Figure 2). Such work modes are furthest away from the optimum ones and as a rule are described by the in-plant instructions. In such situations, let alone the possibility of the instructions being inefficient, they may well describe not all situations that can occur but only ones that designers believe are likely or have already occurred. As of nowadays, the decision in such cases is generally made by the maintenance personnel of the industrial electric power supply system.

Given the example of connection of 6 kV distributing device of the central power distribution station 3 (DD 6kV of CPDS-3) for the time of replacement of 6 kV input for T1 transformer, it is evident (Figure 3) that the difference in voltages obtained on the buses can be quite significant. With the practiced solution,

Figure 2: Diagram of Emergency Switching in Case of Replacement of T1 or T2 in CPDS3



the difference between the rated and the obtained voltage values amounts to almost 2 kV – which does not only lead to sizeable losses in the electric power supply system and to the increased power consumption from the public service network but can also cause the equipment breakdown.

In another example (Figure 4) of studying the normal state of the electric power supply system the difference is not so significant. However, work in the non-optimum mode (not in the rated mode) reduces the equipment life and can lead to an unexpected breakdown of the equipment in case of emergency and cause a series of outages or similar emergencies.

As it is evident from the calculations given (Figure 4), even a slight change of voltage values on buses of the production electric power supply system leads to a significant change of the criterion (i.e. it affects the operation efficiency of the production system).

5. CONCLUSION

In production activity control and planning problems, management and allowance for particularities of electric power supply systems' functioning allows not only saving the electric power consumed but also determining the optimum operation schedules of enterprises (given that the price for electric power and personnel work time differs depending on time of the day), providing for emergencies in production planning, and viewing the problem of justifying the selection of managerial decisions that are obtained by numerical methods with optimization models against time factors.

The decisions obtained are approximated; alongside with that, the problem uses the data of forecasts. So, the problem is put statistically but the model itself can meanwhile combine various types of formalization, which leads to combining the different types of simulation modeling (the criterial one and the counter variable one). Making the models more precise generates the problem of selection of approaches and formalization ways on the basis of the set of already known approaches, ways, methods and models that are put together as a composition (with departure and arrival areas matching) (Post correspondence problem).

When time factor is considered, the operation of system is viewed as a chain of states. The states can both occur and fail to occur (then the system will take an alternative path), which means, the probabilities of occurrence of the states have to be provided for in planning and management (Mylnikov and Kuetz, 2017b).

Using the forecast data in optimum control problems opens up new opportunities for studying the processes taking place in production systems and conditioned by introduction of commercial projects, as well as the economic and mathematical models and methods of managing the said processes.

Figure 3: Change of voltage values in 6 kV bus sections of CPDS-3

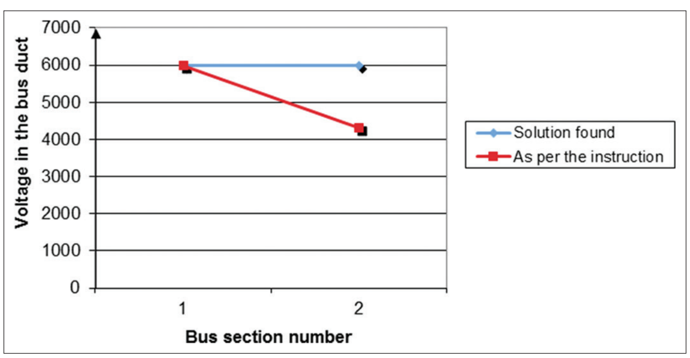
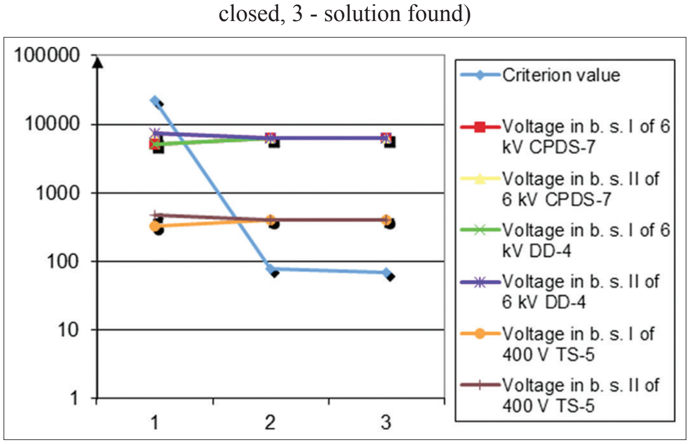


Figure 4: Change of values of the criterion and voltages in CPDS-7 (1 - with intersection switches open, 2 - with intersection switches closed, 3 - solution found)



6. ACKNOWLEDGMENTS

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