Editors

Genadiy Pivnyak
Oleksandr Beshta
Mykhaylo Alekseyev

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ENERGY EFFICIENCY IMPROVEMENT of GEOTECHNICAL SYSTEMS

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Energy Efficiency Improvement of Geotechnical Systems

Editors

Genadiy Pivnyak
Rector of the State Higher Educational Institution "National Mining University", Ukraine

Oleksandr Beshta
Vice Rector (Science) of the State Higher Educational Institution "National Mining University", Ukraine

Mykhaylo Alekseyev
Dean of Information Technology Department of the State Higher Educational Institution "National Mining University", Ukraine

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Energy Efficiency Improvement of Geotechnical Systems – Pivnyak, Beshta & Alekseyev (eds)

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Energy Efficiency Improvement of Geotechnical Systems – Pivnyak, Beshta & Alekseyev (eds)
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Preface

This book incorporates the results of research aimed at enhancing the efficiency of geotechnical systems. The contents of the book cover innovative technologies and approaches aimed at improvement of the technical and economic parameters of geotechnical systems functioning. The focus is on mathematical modelling of objects and processes, as well as developing of state-of-the-art approaches and their control algorithms. The book comprises schemata of solving practical tasks related to mine ventilation and electrical circuit operation, cutter-loaders and mining electrical vehicles. It also demonstrates possibilities of hybrid technologies and IT-methods applications to the work of geotechnical systems. Implementation of the methods and technologies presented in the book will allow the reduction of energy resources consumption by geotechnical systems, and enhancement of environmental and economic parameters of their operation.

Genadiy Pivnyak
Oleksandr Beshta
Mykhaylo Alekseyev
Dnipropetrovs'k
October 2013

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Energy Efficiency Improvement of Geotechnical Systems – Pivnyak, Beshta & Alekseyev (eds)
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Some aspects on the software simulation implementation in thin coal seams mining

G. Pivnyak, R. Dychkovskyi
State Higher Educational Institution "National Mining University", Dnipropetrovs'k, Ukraine

A. Smirnov
Donbass Fuel Energy Company, Donets'k, Ukraine

Yu. Cherednichenko
Ministry of Coal Industry of Ukraine, Kyiv, Ukraine

ABSTRACT: The features of simulation application of the computer systems in a mining production and the methods of their creation and efficiency application are considered. The UML-diagram of general simulation system forming of the mine which contain the basic mining processes of production is offered. This elaboration is opened, that allows connecting the necessary modules of calculation at the change of mine and geological situation in extraction area. It is oriented on the mutual tying up of all technological chain of separate coal extraction enterprise: processes of working face, transporting of the reflected rock mass and other. Such model enables effectively to manage the mining processes.
The special attention is spared the simulation of wallface. This system enables to show out on the display of computer as simulation the real situation or certain model with the proper admittances in relation to authenticity of results and to carry out monitoring and management of mine production processes directly from the mine surface. Examples of such models are made for the separate mine and geological conditions of the mines SC «Pavlogradvugillya» and SC «Lvivvugillya». The economic evaluation of efficiency work of the simulation systems is executed on the mines of the mentioned companies.
KEYWORDS: Simulating, mining, wallface, coal extraction, computer modeling

INTRODUCTION

Usage of computer systems and development of the proper software allows finding qualitatively new solution of complex problems of mining production and registration of documentation of all technical services of mining enterprises. The concentration of mining operations with introduction of mining equipment of a new technological level and introduction in production the mechanized complexes of a new technological level leads to essential change of a stress-strain state of rocks in a zone of influence of mining faces. Dynamic development of mining operations, existence of various geodynamic fields of tension in the anisotropic environment, the variation geological and a structural compound of the massif on a way of advance of a mining face results to necessity of introduction of adequate changes into technology of coal mining and ways of management of mountain pressure. Overall performance of the mechanized complexes depends from timely predicted adjustment of technological parameters and the technical structure, adequate change of geomechanical situations on extracting area.

The increase in length of the wallface to 300 m and an extraction column to 2500 m considerably improves use of the mechanized complex according to its moto-resource. Thus, the volume and time of the reserves preparation is reduced, conditions of excavations support improve and other operational costs are decrease. Negative consequences of such approach - is the high probability of change of a technological situation during functioning of a separate mining face. The areas and forms of geo-active zones, gas emission and water inflow to extraction, coal replacements with rocks and so on, concern to them change of a network of geological disturbances.

The power saturation of the mechanized complexes, reliability of their work allows to increase wallface length to effective parameters of economic feasibility. The advance of a mining face geomechanical the situation can change. Mining operations develop dynamically in depth of a rockmass, in the same direction technogenic fields of stress accumulate. Existence of various geodynamic fields of tension in the anisotropic geological environment influences the direction of a resultant vector of tension which has different value depending on its orientation in the rockmass. Development of mining operations can correspond differently to the greatest a vector of intensity and it is reflected in stability of extraction. Work of the mechanized complex depends on timely predicted correction of technological parameters according to change of a geomechanical situation.

For receiving final products, development the passports of mining work, accident elimination plans, calculation the ventilation of a mine, other labor-consuming technical documentation is also necessary. In this regard, in structure of mine (mine surveying, geology, technical service, ventilation, etc.) there are a large number of highly skilled engineers who are engaged in routine work on processing of all-mine information and drawing up documentation of technological processes. At the present stage of computer technologies their work can be significantly simplified and qualitatively improved. For this purpose it is necessary to shift the sufficient volume of settlement and processing part to computers.

The carried-out analysis of all technical documentation of the mine allowed making its general classification by types of works: geological documentation; surveying documentation; passports of mining works; passports of preparatory works & auxiliary mining documentation. Use the computer systems and development the software allows qualitatively new solution of complex problems of mining.

The authors recommend developing absolutely new system of introduction of computer technologies in mining. The platform of the software is accepted the principles of simulating modeling, rather flexible and that can easily adapt to a changing situation on separate sites of the mining enterprise and unite them into general system.

In our case, introduction provides a mine reconstruction, as simulating models of all processes reflecting a geological, mining and technological situation of the enterprise. The role of the engineer advances to the forefront at decision-making at a concrete stage of performance of separate technological process.

THE ESSENCE OF SIMULATION MODELING OF MINING PROCESSES

With the introduction of the electronic computer facilities work with databases, which are an integral part of any modeling, was significantly simplified. This new stage in development of equipment the carrying out calculations allowed to increase significantly complexity not only separate physical and program components, but also of all investigation phases from introduction entrance yielded by the ways of a conclusion of the end results. Applications of the corresponding information platform, operating system and the program of calculation isn't a problem for the qualified programmer.

The complexity of reproduced technological processes of any production depends on algorithm of carrying out modeling and understanding of physical essence. It is important to develop sequence of elementary actions, each of which to turn into instructions clear to the computer, and any computing the task can be solved. Special programming languages, allow changing the separate computing operations into the corresponding program code. The author doesn't want to receive end products in the form of the computer program but only to develop algorithm of actions which become a basis for such activity.

The first simulating models were developed for economic-mathematical calculations and financial office-work in the mid-seventies the last century. They became the essential help when accounting, both insignificant firms, and large corporations. Over time, the area of their application was significantly expanded and these models began to be applied widely at the cumulating of productions, especially it concerns visual reproduction of separate technological processes.

Simulating models are used in the course of computer simulation of productions. In their basis supervision over results of calculations are put at the various entrance values which are set by variable data within an admissible error. However, the greatest share of simulating models make probabilities, that is containing stochastic elements, and demand essential decisions from the operator (Gryadushchiy 2008).

Check of adequacy of simulating model is reduced to comparison of results of calculations from natural data. When the model is realized in a look the block of the scheme, the UML chart or the software product, corrections of mistakes and operational development of inaccuracies is carried out at an appropriate level of modeling, and then data in the best convergence of results are found. These are the main stages of preparation of simulating reproduction of reality.

Simulating models used those cases when reproduction processes, the phenomena and qualities too difficult that it was possible to apply analytical solutions of an objective. Even at application of linear programming, in many cases, passes reality generalization that on received by decisions it was possible to draw valid conclusions.

The mining production is such a system. It is represented in the form of one of the most difficult models which can be reproduced only at the corresponding combination of components. Creation of simulating models of all technological chain at production, transportation and coal processing on the basis of computer providing allows to predict effectively mining technological processes and to make necessary changes in a case of emergence of non-standard situations.

For these conditions simulation as the tactical analysis which helps to make the decision on need and possibility of carrying out real experiment. It is very important for mining process where difficult technologies and expensive equipment are involved. Simulating modeling unlike other methods of modeling represents easily variable system of representation and reproduction of results. In essence, it is final experiment, but not in real and in artificially recreated conditions.

Reasoning from known representations about a type of modeling their set can be presented in the form of the scheme which consists of three components: ideal idea (zone of real values), zone of simulation and zone of discrepancy of results (figure 1) (Grinko 1991).

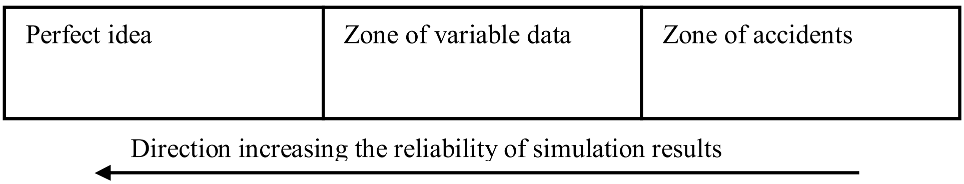

Figure 1. Scheme of an aggregate the simulating model

The structure of simulation modeling is divided into three sectors. "The perfect idea" corresponds real value of object nature. This sector is ideal reproduction of process of modeling. When modeling, actually, has no opportunity to reach 100% convergence to results of "perfect idea"; it is possible to approach the received results to real conditions as much as possible only.

The "zone of variable data" is changeable. Its purpose is the object adaptation - model to real object by means of comparison of fictitious results of model to real results in the conditions of mine. It is necessary in the course of modeling.

The "zone of accidents" is sector of modeling at which the validity of process of modeling isn't observed. It is considered that here has no compliance of results of modeling.

The direction of increase of reliability of results of modeling is indicated the need as much as possible precisely to correspond sector by "perfect idea" is real value of modeling.

The authors suggest approaching more widely to simulating modeling and it is essential to interpret zones of simulating modeling (figure 2).

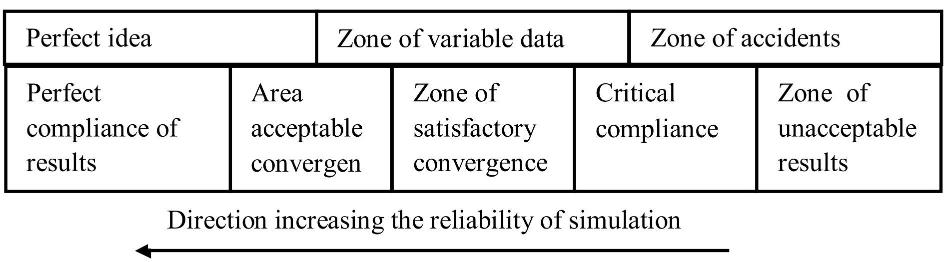

Figure 2. Expanded Scheme of an aggregate the simulating model

When modeling the zone of simulation has to reproduce real data of modeled object as much as possible. Results of researches in "a zone of satisfactory convergence" and "to a zone critical compliances" are expedient for receiving preliminary results about process of modeling and are applied only to acquaintance with modeled by object. In that case proportions of the geoterich sizes or physical properties of object-nature and object-model remain only. They are suitable at the solution of the general fundamental tasks. For example such admissibility can be accepted at visual reproduction of object model. In that case we only reproduce these processes with preservation of the geometrical sizes, physical execution, and we keep proportions in reproduction of the sizes of the capital equipment in the wallface. The same situation is at simulation the schemes of ventilation, the plan of elimination of accident, etc. We don't reproduce the large-scale sizes of extraction, and only we set their schematic location. In a zone critical and satisfactory compliance of results we can examine object interesting to us only.

"The zone of admissible convergence" and "ideal compliance of results" reproduce researches which demand accurate compliance of results of modeling to real results of nature. In these sectors are applied only checked mathematical mechanisms and are used a big number of variable checks.

BASIC DATA FOR MODELING

Application of simulating modeling in the conditions of modern mine is based on simulated reproduction of all of its qualitative and quantitative characteristics: type and mine structure; technologies of production, scheme of opening of a mine field; schemes of preparation of mine or parts of mine fields, extract systems; sequence of working off of layers; planned schedule of extraction of reserves; type of underground transport, scheme and way of ventilation; numbers of blocks of a mine field in simultaneous work; numbers of the horizons, floors, panels in a mine field; number of extraction fields, etc. Common approach to a choice of parameters and elements of mines is that at the beginning is planned previously values and characteristics of parameters of mine, and then these values and characteristics are consistently specified on the basis of calculations and mutual coordination.

Some parameters and schemes can be unambiguously determined by mining conditions. If various values of parameters and various decisions are possible, options which are estimated by the accepted criteria of efficiency. The compare parameters of mine on the basis of the technical and economic analysis and specifies in the course of simulating reproduction. All these processes logically connected in system of the automated control of the mining enterprise (figure 3) that allows to analyze systemically a condition of mine and to introduce necessary amendments into mining process.

Creation of simulating model of all mine in the specified volumes demands not only big efforts at the level of the developed structure of programmers, but also high system opportunities of the software. Therefore at design of such difficult information system it is offered to break it into components, each of which is considered separately. Two various ways of such splitting into subsystems are possible: structural (or functional) splitting and object (component) decomposition.

The essence of functional splitting consists of system "the calculation program - variable basic data - algorithms of performance of actions". At functional decomposition of program system its structure can be described by the flowcharts which knots are "the processing centers" (functions), and communications between knots describe movements of data.

Object system division still call component that found reflection in the special term:" the development based on components". Other principle of decomposition is thus used - the system breaks into "an active essence" - objects or components which interact with each other, communicating and acting to each other in the relation "the client - the server".

The server is the dispatching service of mine or online support of information product by his producers through worldwide network the Internet. The message which the object, defined in its interface can accept. In this sense the message parcel "object - the server" is equivalent a call of the corresponding method of object.

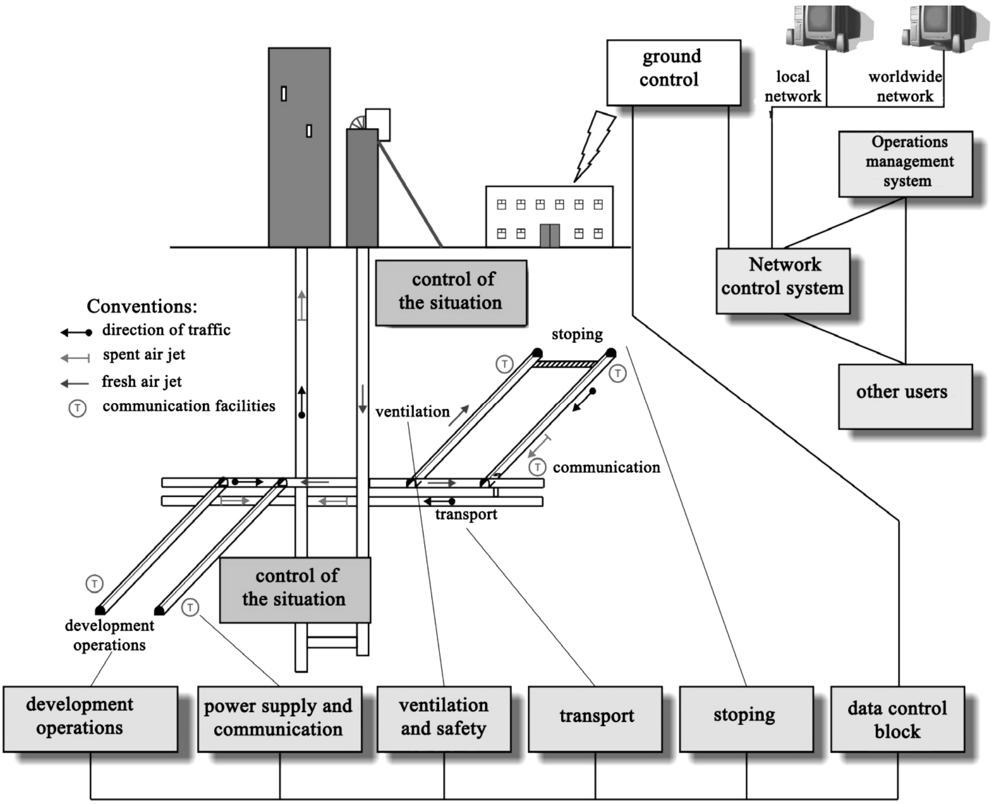

Figure 3. System of the automated control of the mine

Authors suggest accumulating on system "mining works», which is to rise by level of simulation wallface: mining face, preparatory workings, bench connections with drifts and lithologic a structure of lateral rocks.

For this system basic data for modeling are two major factors - a mining-and-geological structure and the technological situation in a wallface.

The lithologic difference is put by means of display of the planes of division on stratification of rocks (figure 4). Difference of points in the vertical plane (U) on length of an extraction column (L) is described by means of "soft" mathematical models in the form of curve various orders:

$U = f(L)$.

On received on two extraction drifts (onboard and conveyor) the geological structure of the rockmass is formed. It is corrected by means of connection to modeling of these prospecting wells, containing in limits of a considered extraction column.

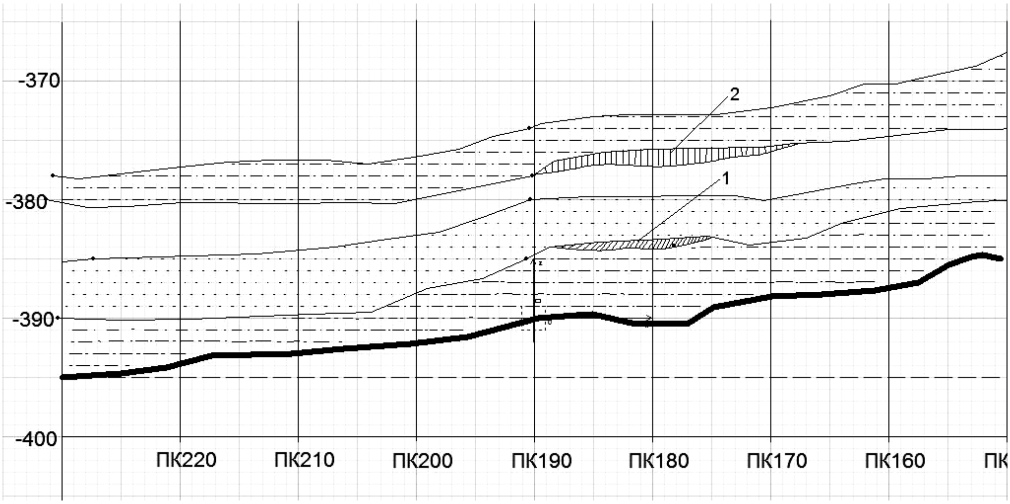

Figure 4. Cross section of geological thickness by one of the site drifts

Geological disturbances, complexity of a structure bring to very difficult the mathematical mechanism of input of entrance data and construction on the equations of a geological difference of the rockmass. Therefore the authors suggest entering data manually. Thus, it is possible to reflect rather in detail sharp changes in a geological structure of the massif. It is promoted also by the software applied to reproduction of graphic objects of interpolation of lines, creation of isohypses etc.

PROCESSES OF THE HIGH-MECHANIZED EXTRACTION

For modeling the process of performance of operations so-called charts of activity are used. The graphic component applied in them is similar to condition charts as on activity charts also there are designations of stationary conditions and high-quality transitions of system. Difference consists in semantics of conditions which are used for representation not static character of system, and dynamics of its change and in absence on transitions of a signature of events. Each action of the chart corresponds to performance of some elementary operation, and transition to the following condition works only at end of a definite purpose. Graphically the chart of activity is submitted in the form of the activity schedule which tops are actions, and arches - high-quality transitions from one condition to another.

Charts of activity play an important role in understanding of modeled processes. Traditional flowcharts of algorithms used for this purpose possess serious restrictions in representation of parallel processes and their synchronization. Application of paths and objects opens additional opportunities for evident representation of processes, allowing specifying simulated processes.

Thus, process of the object-oriented analysis and design of difficult systems is represented as sequence of iterations of descending and ascending development of separate charts. In case of the standard project the majority of details of realization of actions can be known in advance on the basis of the analysis of existing systems or the previous experience of development of systems prototypes. For this situation ascending process of development will be dominating. Use of standard decisions can significantly reduce time of development and prevent possible mistakes at implementation of the project.

When developing the project of the new system which process of functioning is based on new technological decisions, the situation is represented more difficult. Namely, prior to work on the project can be unknown not only details of realization of separate actions, but also their content becomes a development subject. In this case descending process of development from more general schemes to the charts, specifying them will be dominating.

The activity chart as well as other types of initial charts, doesn't contain means of a choice of optimum decisions. When developing difficult projects the problem of a choice of optimum decisions becomes actual. Rational expenditure material and the labor costs spent for development and operation of system, increase of its productivity and reliability often define the end result of all project. In such situation it is possible to recommend use of additional resources and the methods focused on analytics-simulating research of models of system at a development stage of its project. The chart of activity of system of the automated design by mining operations (figure 5) allows unwinding all actions which we will carry out in the course of modeling and their sequence in space and time.

At the first stage of activity passes the analysis and reproduction of mining-and-geological conditions of a bedding of stocks. For this purpose graphic and numerical information serves.

To graphic information belongs:

- three-dimensional display of a mine field (display of contacts of geological layers with a binding to system of coordinates);
- drawing of geological disturbances;
- receiving geological cuts.

To numerical information belongs:

- thickness of a coal and of a rock layer, their strength, water cutting, existence of inclusions, etc.;
- numerical characteristics of a bedding of coal layers (capacity, hade, durability, fracturing, etc.).
- angle tectonic and natural fracturing, orientation of rather mining works.

To reproduction of a mining situation at working off of stocks it is used the statistical data connected with process of coal mining. Therefore at this stage the database and the analysis of technology of working off of stocks is applied.

Databases of technical providing include:

- types of fastening of excavations;
- type and structure of the mechanized complexes;
- ways of protection of excavations;
- mining equipment.
- ways of fastening of connections of a bench with drifts

In the analysis the technology of working off of stocks has to be in details considered and reproduced the following information:

- schemes of opening of a mine field;
- way of preparation of reserves;
- development system;
- direction of reserves extraction.

At the second stage the analysis of existing equipment and technology of production of stocks of coal on mine is carried out. It is carried out by a well-known technique of design of productions on mine:

- choice of the scheme of opening of a mine field, way of preparation and system of extraction
- mining-and-geological condition.
- three-dimensional model of a mine field
- chosen mining equipment.

At a stage of increase of efficiency of production of stocks of coal the choice of versions of possible technical and technological solutions is made and settled an invoice their economic feasibility.

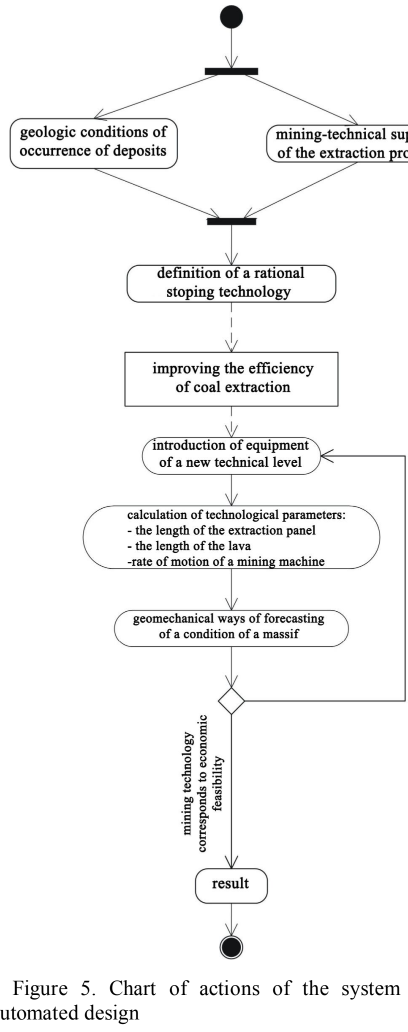

Figure 5. Chart of actions of the system of the automated design

Each technological introduction has to be based on development scientific and technical progresses and the latest development in system "science - design - production". Therefore, at this stage the equipment is carried out most suitable. Main objective of this stage is the analysis of technology of development for elimination of "bottlenecks" and increase in capacities.

Further for each possible variant it is carried out the calculation of technological parameters of production:

- length of an extraction column;
- wallface length;
- speed of of the cuttingloader, etc.

According to chosen technological parameters of working off of stocks zones PGT pay off, are displayed in three-dimensional model and checked on compliance of possibility of application and safety of performance of technological processes.

Process of a choice of the corresponding technical and technological improvement is carried out to full economic feasibility from the point of view of the separate mining enterprise. Iteration of recurrence of conducted researches depends on complexity of the system, an available know-how and necessary accuracy of the received results.

All system of simulating representation of system of modeling of the high-mechanized extraction of thin coal layers consists of the chart of classes which serves for representation of static structure of model of system in terminology of classes of object-oriented programming. The chart of classes, as a rule, is static representation of object model or system model. At detailed level they are used for generation frame a program code in the set programming language, and also for generation of SQL DDL of the offers defining logical structure of relational tables.

For the description of dynamics of system behavior charts which share on charts are used:

- conditions;
- activities;
- interactions (consist of charts of sequence and mutual exclusion charts)
- realizations (consist of component charts and expansion charts).

It can reflect interrelations between essence and evident results, and also describe internal reproduced objects and structure and types of the relations. On this chart information on temporary aspects of functioning of all system isn't specified. The chart of classes is further development of conceptual model. The chart of classes is the certain count which tops are "qualifier" elements which are connected by the various structural relations. The chart of classes can contain interfaces, packages, communications and separate software packages. When speak about this chart, mean static structural model of designed system. However, it depends on changes in space and time.

Process of development of the chart of classes takes the central place in object-oriented modeling of difficult systems. From ability it is correct to choose classes and to establish between them interrelations often depends not only success of process of design, but also productivity of implementation of the program. As the practice shows, each programmer in the work seeks to make use to a certain measure of already saved up personal experience when developing new projects. It is caused by desire to reduce a new task to partially solve to use the checked fragments of a program code and separate components.

Such approach allows reducing significantly terms of implementation of the project. After development of the chart of classes process of modeling can be prolonged in two directions. On the one hand, if behavior of system trivial, it is possible to start development of charts of cooperation and components. For difficult dynamic systems the behavior represents the most important aspect of their functioning. Specification of behavior is carried out consistently when developing charts of a condition, sequence and activity.

Developed chart of classes of system of functional design isn't the final product in the form of a separate software package in language of computer programming. It contains all necessary components for simulating reproduction of mine at high-performance extraction of thin and very thin coal layers. The authors managed to realize only separate parts and to connect them in uniform simulating system.

SIMULATION REPRODUCTION PROCESSES OF MINING

The authors offer completely recreate a computer simulation model of the entire mine or her individual site that enables effectively to monitor mining operations and proactively make the necessary technological changes in the process of coal mining. Transverse sections of the geological strata for roadway and structural columns studied areas is the initial information for the simulation of the geological structure of the rockmass and mines that are within these limits. For example, we give a reflection on the plane simulation of lithologic structure (Figure 6).

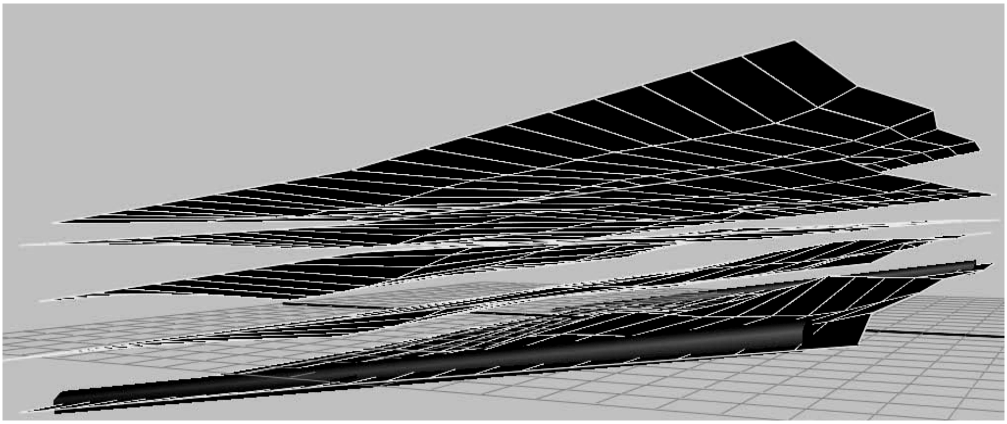

Figure 6. Simulation of a lithological structure

To determine the length of rational walface authors used a technique based on determining factor geological and structural buildings massif (section 4). Part of this work was to mine "Stepova" JSC "Pavlogradugol" using mechanized complex KD - 90. Screenshots of the software are shown in Figure 7.

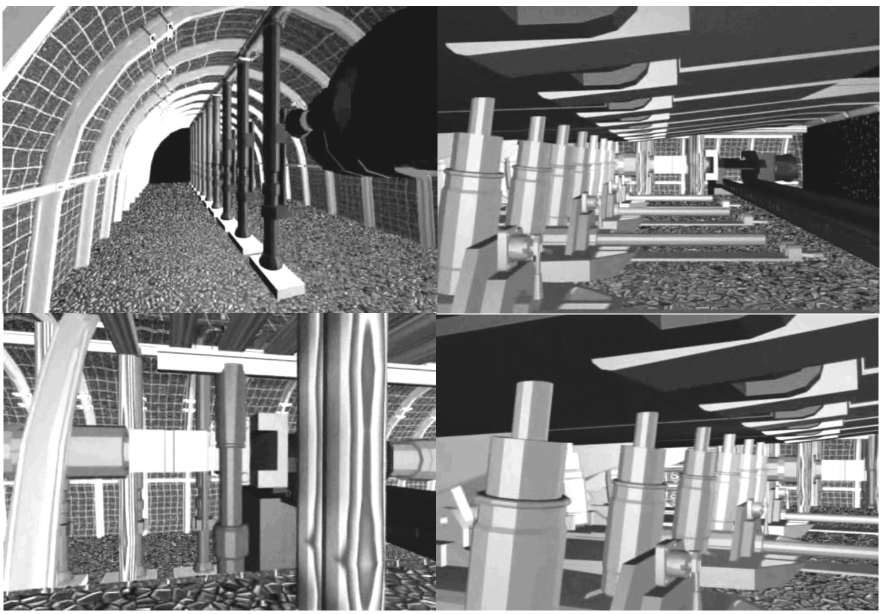

Figure 7. Screenshots of simulating representation of a technological situation on a mining stope site

The forecast of the condition of the rockmass is carried out by the analysis of geological and surveying documentation and monitoring mining pressure. It is basic data for determination of technological parameters of a mining face, but doesn't consider a condition of mining equipment. Technical characteristics of the mechanized complexes are focused on average values of behavior of the rockmass and consider frequent changes of mining-and-geological conditions insufficiently. The technical system of the mechanized mining face works independently and its condition is partially estimated when performing scheduled or repair work.

Timely replacement of the component of technical or technological system depends on anticipation material service. Its actions have discrete character, coincides with planned indicators of mining. Between separate services of mine not coordinated actions which make a problem when planning intensive development of mining. Absence of algorithm of interaction of separate subsystems (geological and surveying, monitoring of geomechanics, transport and other) which defines a form and geometrical parameters of technological system and allows to interfere and correct quickly work at intensive extracting coal seam.

Reasoning from a condition of coal-mining area of Ukraine and need of its stable further development, development of the scientific principles of formation of simulating models in mining is very actual task. The results of works is planned to introduce at the enterprises of mining branch of Ukraine, the preference is given to coal mines of Ministry of Fuel and Energy of Ukraine.

CONCLUSIONS

The scheme of simulating model allows expanding considerably a scope of computer programs at simulated reproduction of difficult processes high-mechanized production of thin and very thin coal layers. Creation of computer simulating models of all complexes of mine or its separate structural units gives the chance to operate effectively the mining process. Simulating is very effective, flexible and dynamic method of representation of difficult systems that is an integral part at reproduction of difficult processes of mining.

Possibility of a combination of various modules within simulating model which can be already existing information appendices or author's development of certain researchers significantly is expanded by possibilities of this type of modeling.

Creation of simulating model of mine doesn't aim at development of a final information product, in the form of a package of computer programs, and only accurate system of its realization, including all mathematical mechanisms, used in calculations.

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Normalization of voltage quality as the way to ensure energy saving in power supply systems

G. Pivnyak, I. Zhezhelenko & Yu. Papaika
State Higher Educational Institution "National Mining University", Dnipropetrovs'k, Ukraine

ABSTRACT: The article deals with the problem of electric power quality. The problems in power systems accompanying losses in voltage quality are analyzed. The main causes of quality losses are identified. The technique of detection and evaluation in reference to additional loss in electric networks is given. The conditions which provide the emergence of resonances in the networks with higher harmonics are described. Measures to limit the higher harmonics are analyzed. The variety of harmonic filters is described. Findings which prove energy savings observed at normalized quality rating are presented.

1 INTRODUCTION

Coal industry is considered the top priority in the economy of Ukraine, specifically in forming the index of the gross domestic product. Vertically integrated company DFEC (Donetsk Fuel and Energy Company) is the power engineering leader in Donetsk and Pridneprovs'k region. Heavy investments have been made in the modernization of mining and energy equipment to improve the efficiency of coal mining since the corporation of coal mines "Pavlogradugol" has joined DFEC. The electric drive with frequency response has become more widely used at powerful electricity generating plants (main mine fans (MMF), all types of hoisting units, belt haulage).

Intensive installation of power converters in the power-supply system of mines results in negative consequences such as electromagnetic interferences (EMI), mostly harmonic nature. Higher harmonics in power systems were considered to be the main form of electromagnetic interference up to the end of the previous century. At present, due to the wear and tear of equipment and significant deterioration of the main facilities of electric-power industry (by 70-80% in Ukraine and Russia), the voltage quality derating has become an urgent problem. Voltage quality increase in electric power systems is a matter of greate importance in advanced economies as well. It is estimated (Zhezhelenko 2004; Zharkin 2010), that EU industry and community on the whole lose about 10 billion euro's per year due to power quality problems, while the costs of preventive measures are less than 5% of this amount.

It should be noted that the problem of power quality in the mains of Ukraine is extremely specific. Thus, for example, in all industrialized countries of Western Europe, the connection of powerful non-linear loads which can distort the current and voltage curves of power supply is allowed only if the quality of supplied power satisfies specification limit and there are appropriate adaptors. At the same time, the total capacity of the newly introduced non-linear loads should not exceed 3 - 5% of the total load capacity of the power company (Zhezhelenko 2012). The situation is quite different in Ukraine where connection of powerful single-ended and non-linear electrical receivers is chaotic. The developed system of higher power rates, imposed for deteriorating the voltage quality by the consumer, is not efficient, which results in systematic voltage derating, increased electric loss, the occurrence of resonance processes at high frequencies in the network capacity.

The paper aims to analyze the current situation as regards power quality in the networks which supply profitable mining enterprises and to identify the conditions of resonance emergence. Special attention is paid to the evaluation of power consumption modes at mines where adjustable filter compensating units are installed.

2 THE PROBLEM OF HIGHER HARMONICS

Power quality rating (PQR) is one of the main problems concerning electromagnetic compatibility of consumers.

Higher harmonics in electrical networks are undesirable due to a number of consequences for the power supply system of the mine, i.e. they have a negative impact on the technical state of electric equipment and deteriorate economic parameters of its operation. This contributes to the incidental loss of power and energy, which in turn affects the thermal regime of electrical equipment, complicates compensation of the reactive power with static capacitor banks, electrical machinery and apparatus service life is reduced due to the accelerated wearing and tearing of insulation, system and networking equipment failures and malfunction of telemechanic equipment is observed.

The impact of higher harmonics is implicit and has a cumulative effect, so the consequences, such as the insulation defect of electrical machines and cables, could be expected within a certain period of time. Voltage waveform distortion affects the occurrence and behavior of ionization processes in insulation. In the presence of gaseous inclusions in insulation the process of ionization occurs, the physical essence of which is to generate a space charge and its subsequent neutralization. The neutralization of the charges correlates with energy dissipation which results in electrical, mechanical and chemical effects on the surrounding dielectric. The above mentioned facts are considered to be the causes for local defects in the insulation which reduce the service life of the insulation. In the presence of higher harmonics in the voltage curve the insulation wear and tear process is more intensive, especially in cables and capacitors. Some authors argue that if the value of the higher harmonics accounts for 5%, then tgδ of capacitors doubles after two years of their operation.

Additional loss both of active power and electric power is detected during the flow of harmonic currents through the network elements and the electrical equipment of consumers.

The greatest value of active power loss caused by the higher harmonics is observed in transformers, motors, generators, overhead power lines and cable transmission. The increase of active resistance of these elements caused by the frequency step is proportional to the magnitude $\sqrt{\nu}$, although it is somewhat of imprecise approximation (Zhezhelenko 2004). In some cases, additional loss may cause unacceptable overheating and failure of electrical equipment. The value of the additional loss in active power and energy is determined by the mode of operation of electrical equipment and the level of the higher harmonics in the network.

Additional value of active power loss in the air and cable transmission is defined as:

$$\Delta P_{add\nu} = 3 \sum_{\nu=3}^{n} I_\nu^2 R_\nu , \quad (1)$$

where I_ν -the current of ν-harmonic; R_ν - active resistance of power lines at the frequency of ν- harmonic.

In general, we recommend determining the active resistance of overhead power lines taking into account the function (Zhezhelenko 2012):

$$R_\nu = R_2 K_r K_{r\nu} , \quad (2)$$

where $R_2 = r_0 l$ - the active negative (phase-) sequence resistance of the power lines; $K_r = \sqrt{\nu}$ - a coefficient which takes into account the dependence of active resistance on frequency; $K_{r\nu}$ - the correction factor, which takes into account the distribution of the parameters in the equivalent circuit.

Additional energy loss is determined in accordance with the largest power loss (the simplified method recommended if there is reliable information about power consumption):

$$\Delta A = \Delta P_{add\nu} \cdot \tau_{max} \quad (3)$$

where τ_{max} - the time of biggest loss, defined by the time of the heaviest loads T_{max}, which had been obtained in the analysis of real graphs of harmonic currents (daily T_{max} = 15 hours, annual T_{max} = 6000 hours).

The main regulatory document where the requirements to the quality of electrical energy in the power networks of general purpose are specified is GOST 13109-97. On 01.01.2013 Russia has adopted a new State Standard which takes into account the electromagnetic interference in the operation of electrical equipment of the new generation.

Under this Standard, a part of PQR describes EMF in steady conditions of equipment operation as far as electric power supplier and consumers are concerned due to the peculiarities of the process of production, transmission, distribution and consumption. These ones include voltage and frequency deviation, distortion of voltage waveform harmonicity, voltage unbalance and fluctuations. For their normalization the permissible PQR values have been determined.

Another part of PQR involves short-term EMF resulting from commutation processes, thunderstorm and other atmosphere phenomena as well as post-emergency modes: voltage drops and pulses, short interruptions in power supply. The Standard does not predetermine any acceptable numerical values for such cases.

PQ standards according to GOST 13109-97 are the levels of electromagnetic compatibility (EMC) for conducted electromagnetic interferences (EMI) in general-purpose power supply systems. Adherence to the standards provides EMC of general-purpose electric networks and power grids of consumers (receivers of electric energy).

Compliance with the power quality standards makes possible not only to save fuel and energy resources, but the other types of material resources as well, a part of which, at a reduced PQ, has to be spent on products rejected as defective or recyclable ones (Zhezhelenko 2004, 2012).

Reduction of upper harmonics levels (UH) in electrical networks is a part of the general task aimed at minimizing the influence of non-linear loads on the mains supply and at improving the quality of electricity supply in power systems of enterprises. Comprehensive solution to this problem based on the use of multi-function devices, is economically more appropriate than, for example, the use of measures to improve the network transformer current waveform. Resonant filters, known as compensating filter-devices (CFD), which, along with reduction in the levels of UH generate reactive power into supply network are the example of such multifunctional devices.

When connected in parallel LC-circuits are tuned to the frequencies of individual harmonics, resonant CFD works in practice. Deficit of reactive power in substation buses in this case can be completely compensated by means of CFD capacitor banks, moreover the installed power of capacitors is used by 80-90%. Thus, CFD are the simplest and most cost-effective filters, and this fact ensured their widespread use.

If the range of the power load in the shaft involves both power collectors and frequency converters, then unwanted (hazardous) resonance phenomena occur caused by the presence of an oscillatory circuit such as mains supply – static capacitor banks (SCB). The peculiarity of these modes is the correlation between the stationary electrical equipment units in the shaft (main fans, hoisting systems, transport) and technological cycles.

To analyze and evaluate resonance phenomena in power systems of mines, it is necessary to model frequency characteristics (frequency response FR) of electric circuit in view of mutual resistance (conductivity) of its individual components (off-take cables, transformers, motors). The resulting frequency responses will help identify the area where resonance frequencies appear when SCB of certain capacity is connected to the real-mode power supply system (the plant capacity, the number and parameters for off-take cables are taken into account).

Frequency response calculation algorithm has been worked out and tested by practical measurements. Initially, the simulation requires the most accurate information about the parameters of the power supply system of mines (length and cross section of overhead power lines, power transformers' capacity, types of current limiting reactors, SCB power (the resistance of the system verified by testing). Then electricity systems with typical (normal) mode of operation are chosen and regimes that are observed during repair-and-renovation operations or post-fault operative switching are identified. Next, a replacement scheme for each analyzed mode is made up and the resultant RLC network impedance and the load are determined by electric and technical calculations.

To construct a frequency response, one can use different mathematical approaches (experimental methods based on active or passive experiment and involving spectral analysis, the use of wavelet transformation for experimental identification, determination of network frequency responses using the correlation moments of currents and voltages). All these methods require active intervention in the existing power supply system of mines, so the principle of engineering calculation of frequency response is used in this research. If there are reliable baseline data, this approach will give acceptable results for the evaluation and development of technical recommendations to improve electrical systems.

The obtained frequency responses clearly show the areas of resonance occurrence and help take decisions whether to install SCB, active or hybrid filters, which methods for SCB protection to employ, etc.

3 FREQUENSY RESPONSE IN POWER SUPPLY SYSTEMS

For example, calculation of frequency response in power supply for mine "Blagodatnaya", at normal (each high voltage input works separately) and post-fault operation modes (only one input is enabled, the section switch is in the "on" position).

There are the basic elements involved in resonance as shown in the equivalent circuit (Fig. 1-b): the mains power supply, battery cosine capacitors and valve load (VLC with the converter).

The connection of capacitor banks results in a non-linear character of the frequency response (Fig. 2-3). Nonlinearity of the characteristics is determined by a Q element of the supply mains (the ratio x / r).

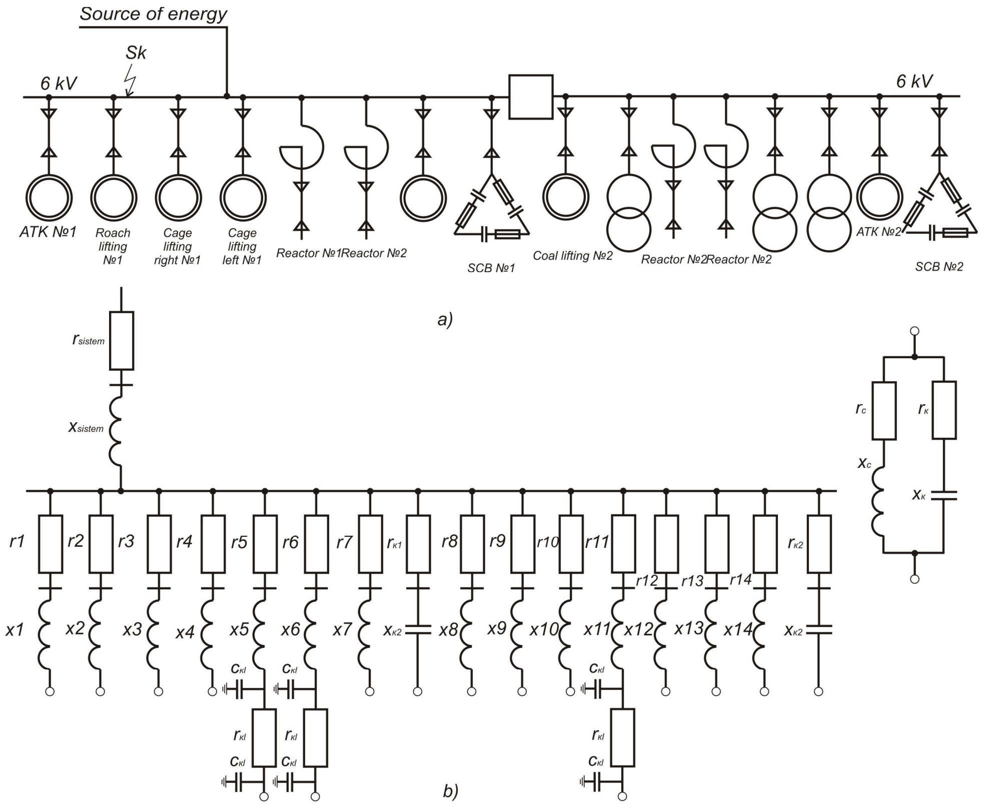

Figure 1. Electrical circuit of the nains (a), equivalent circuit (b) and the equivalent circuit for the post-fault operation of the mine

Nonlinearity of the frequency response of supply mains is explained by the fact that when the SCB is connected, parallel LC - circuit consisting of inductive reactance of supply mains and capacitive resistance of condenser is formed.

The equation for the frequency response of LC circuit of supply mains, forming the basis of the resonance phenomena model, is as follows:

$$Z_{1v} = \frac{(r_c + jx_{cv})(r_k - jx_{kv})}{r_c + r_k + j(x_{cv} - x_{kv})} = \frac{r_c r_k (r_c + r_k) + x_{cv}^2 r_k + x_{kv}^2 r_c}{(r_c + r_k)^2 + (x_{cv} - x_{kv})^2} + j\frac{x_{cv} x_{kv}(x_{kv} - x_{cv}) + r_k^2 x_c - r_c^2 x_k}{(r_c + r_k)^2 + (x_{cv} - x_{kv})^2} \quad (4)$$

where x_{cv} - the equivalent inductive resistance of supply mains at ν-harmonic frequency;