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# Selected information technology tools supporting for maintenance and operation management electrical grids

W.KAMRAT
Gdansk University of Technology, Faculty of Electrical and Control Engineering, Power Engineering Department,
11/12 Narutowicza Street, 80-233 Gdansk, Poland

**Abstract.** The paper presents the main issues of management of electrical grids. Selected information technology tools supporting for electrical grids maintenance are presented. In electrical infrastructure maintenance of power companies the geographic information systems are increasingly used to support the management of theirs resources. Their functionalities in terms creating comprehensive databases for electrical infrastructure of power sector are described. The important information technology tools regarding spatial systems for supporting maintenance and operation management electrical grids and the conditions of their implementation are presented. This paper also attempts to innovative multidimensional evaluate the technical and economic benefits resulting from the use of modern information technology tools for the management of energy infrastructure.

**Key words:** Electrical infrastructure maintenance and management, Information technology tools, Spatial information systems.

## 1. INTRODUCTION

The specificity and complexity of modern power network management cause the need to use specialised software and tools. Therefore, there is a problem of processing and analyzing data to transform them into such a form that they can be used in decision-making processes. Archiving, modification, presentation and management of data related to the power grid is a serious problem for rational maintenance, as classic database applications are not able to perform these tasks satisfactorily. The exploitation of modern energy systems naturally forces the rationalization of energy use, increasing the reliability of power supply and reducing the costs of production, transmission, and distribution of energy. One of the significant problems is the management and monitoring of energy infrastructure, which allows for a significant reduction in costs related to the maintenance of equipment, installations, and energy facilities in operational efficiency. The dynamic development of information technology that has taken place in recent years has enabled the creation of modern monitoring, control, and supervision systems as well as management of extensive power networks. One of the features of modern systems of this type is the increase in the degree of their functional and hardware integration. Systems built for the needs of network enterprises provide a whole range of services in the field of:

- ensuring constant supervision over the operation of all elements and devices in the power network,
- collecting, processing, and sending information about the processes taking place in it,
- real-time observation of all parameters of utilities and devices in the transmission network,
- control of actuators from a central dispatch point,
- archiving specific information about processes and measurement values in relevant historical databases,
- creating multidimensional "process data warehouses" by integrating historical databases with current, configuration, business, event and database databases and their further processing.

The above-mentioned systems most often include the following subsystems and systems:

- automation and telematics,
- digital and analog data transmission,
- data processing, collection, and visualization

Information technologies used until recently in energy enterprises were characterized by a low degree of integration. Characteristic was the creation of large numbers of small databases, often containing many overlapping data, for the needs of individual users. Due to the incompatibility of the software, it was common to "manually" transfer data between the various levels of management and operator control. Observing the rapid development of computerization, it can be predicted that modern management support systems and modern information technology (IT) enable full and economically justified integration of the above tasks by creating a common IT system suitable for use with wide range of programs for data collection, enables the implementation and convenient use of a global information management system process as well as technical and economic data about the enterprise. The exploitation of modern energy systems naturally forces the rationalization of energy use, increasing the reliability of power supply and reducing the costs of production, transmission, and distribution of energy. One of the significant problems is the management and monitoring of the energy infrastructure, which allows for a significant reduction in costs related to the maintenance of equipment, installations, and energy infrastructure facilities in operational efficiency.

## 2. General characteristics of modern tools and information technology in the power industry

In recent years, significant use of modern information technologies in the power industry can be noticed. Significant progress was seen in the management of large data resources (Big Data)[1]. This solved many problems in planning the development of power systems, operational management and management of the maintenance/operation of grid systems [2]. The importance of issues and problems in the application of IT tools in the power industry is shown by the studies and work of the D2 Study Committee of the Large Electricity Networks CIGRE (Conseil International des Grandes Reseaux Electriques) during the 48th Session 2020. The leading topics (Preferencial Subjects) deserve special attention, namely [3],[4]:

•PS 1 - Influence of new information and telecommunication technologies on applied solutions in the power industry,
•PS 2 - New cybersecurity challenges in the changing power sector,
•PS 3 - Increasing operational efficiency through the use of telecommunications technologies based on Packet Switching.

Modern IT tools support systems for managing energy resources in the design and implementation of new grid investments, as well as modernization, planning and running the current operation of the grid and handling emergency and crisis situations[5],[6],]7],[8]. They also enable optimization of network infrastructure maintenance costs and increases work efficiency. The modular structure and integration possibilities guarantee the implementation of the system tailored to the individual needs of a network company and obtaining maximum added value. The implemented system becomes the basis for implementing the concept of intelligent energy networks (e.g. Smart Grid)[9],[10]. Support for business processes is provided in the following areas, such as:

•network documentation,
• failure handling,
•service delivery,
•network expansion planning,
•maintenance of the operational efficiency of the power grid,
•network control,
•technical calculations,
•network and business analyzes.

The power industry (due to large amounts of measurement data, process complications and high rotation) is an ideal sector for comprehensive implementation of IT systems that can bring significant savings. There are new tools and applications that need to be integrated at the same time into the common operating system. Often even the organizations themselves change their structures, striving to consolidate and standardize processes. What connects IT systems in the power industry today are connections throughout the entire process chain: fuel consumption, generation, transmission, distribution, electricity trading, corporate and retail customer service. These processes are inextricably linked with specific market regulations. On the one hand, technical limitations and, at the same time, striving for more and more competition force cost reduction. The offered and implemented IT systems for the power sector are the result of many years of cooperation with leading Polish and foreign companies. In general, the product portfolio can be arranged in a classic pyramid scheme for the electricity sector. At the base, systems are supporting individual devices operating in a power plant or elements of the transmission and distribution networks, and upwards - systems managing the operation of power units, often equipped with optimization or diagnostic modules. Another part of the pyramid are IT systems that integrate data at the power plant and the whole concern level. At the top of the pyramid are applications supporting management processes for managerial staff, based on a comprehensive analysis of all data available in production, transmission and trade, which are subjected to advanced processing using Business Intelligence tools. Specialized solutions of large producers are integrated for the power sector in such product areas as:

• MDM (Meter Data Management) - central measurement databases,
•AM (Asset Management) - management of repair systems,
•Data banks • the largest data servers,
•Authorization and authentication systems (including biometrics),
•Application integration via a data bus (SOA).

It is this last area that is becoming more and more critical for all energy companies. With the advent of a huge number of applications and data exchange modules, it is necessary to organize processes - of course with the help of an integrated data bus. In addition, the role of cloud computing systems is becoming more and more important: private cloud (energy corporations, process centralization, e.g. commercial or technical customer service, SSC - here all applications and information systems adapted to be implemented in the SSC and using the data bus), public cloud - an offer for smaller companies conducting specific activities (eg trading companies and "WIRE on DEMAND" - a very popular and highly rated by customers possibility of full transfer of compiled - and requiring expensive IT support - software for energy trading). It is worth emphasizing that the electricity sector, through its links with the fuel sector and offering electricity at a reasonable price to manufacturing companies and private customers, determines the competitiveness of the entire economy. Modern tools, technologies and information systems, which significantly support their rational operation, are of great importance in the processes of managing the power grid infrastructure[11]. A special role here is played by the modernized/upgraded geographic information and power grid monitoring systems, which have been used for several years and are described later in this article.

## 3. Geographical Information Systems

Computer technology has created a new quality in management, because of the efficiency of systems and increase the possibility of their integration. The culmination of activities in this area have the creation of the spatial information systems, whose basic property is the spatial location of data. This means that based on system data, one can precisely determine the location of the recorded field object, and with it spatially position a selected set of information describing this object. The range of applications of these systems is wide. Such the systems can be used to manage the power grid, to plan its optimal development, and generally to support the implementation of the basic function of managing network assets [12],[13],[14]. The mentioned systems can be used in many applications, including: planning the construction and operation of high voltage power lines [15], programming cooperation of transmission and distribution systems on the European electricity market [16],[17] optimal strategies of electricity contracting, analyzes and research on energy reliability and security [18] or the issues of wind farm location due to their aerodynamic impact on the grid infrastructure [19].

There are many solutions for geographical information systems. Often, power engineering creates them on its own according to needs. New quality in this area is information systems - Geographical Information Systems (GIS), which significantly support the management of data on the power grid infrastructure.

One of the more common and effective geographical spatial information systems is the SICAD system (Siemens Nixdorf Computer-Aided Design), developed for information, documentation, and power planning and statistics[9]. From the beginning, SICAD has been developed in close cooperation with users of the energy industry, which is why in Europe and the world SICAD is one of the leading information systems, so in Germany where it comes from occupies 50% of the market. In connection with the above, this system was chosen for more detailed characterization. The SICAD system provides convenient and quick creation, updating and analysis of plans as well as additional technical descriptions (so-called non-graphical or descriptive data) that can be attached to plans illustrating, e.g. technical infrastructure. The uniformity of the digital information system made in a modular form makes it very user-friendly, offers extensive updating options and a full range of cartographic functions, which response to its practical needs. Even a user without detailed knowledge of how to use GIS programs can quickly masterwork in SICAD. The digitizer menu and procedures (macros) allow the additional user help [20].

The geographical documentation and the information system created in SICAD meets certain basic requirements, namely:

- functional, logical, and actual representation of the network structure,
- permanent and reliable data storage in the network structure,
- full integration of graphic and descriptive information.

To manage, analyze and control all geometric elements and alphanumeric data, SICAD uses a geographical database (GDB) relative to a given use area. A geographic database is usually defined as a rectangular area, with the size of the geographical database depending on the area it describes and the density of information it contains.

For this reason, SICAD implements a processing function that automatically divides the entire areas of the GDB geographical database into cells (Fig. 1). This structure has many advantages, namely[20],[21]:

- data access time is significantly accelerated, regardless of the size of the GDB database,
- work in the smallest possible areas, which means a short response time, which reduces the costs of the entire system,
- requests for descriptive data are accelerated by specifying their geographical description,
- smaller map areas are particularly flexible and convenient to operate,
- graphical output on the plotter can be fully optimized.

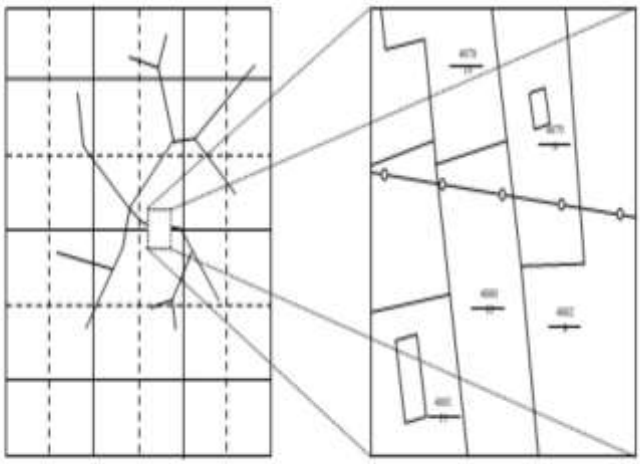

**Fig.1.** The cell structure of a geographical database

The characteristic features of the SICAD system are:

- the possibility of distributed storage and management of data in computer networks using a platform that supports the TCP / IP protocols,
- possibility of installation in various operating systems,
- cooperation with relational databases, such as Informix, or Oracle,
- ease of creating and adapting applications to customer needs,
- a very rich set of cartographic functions,
- possibility of cooperation with other CAD / CAM systems,
- the ability to create complex structures from graphic elements.

The SICAD geographical spatial information system allows to define various types of graphics with information in various fields. They can be superimposed on each other for graphic processing purposes. The system has a full set of access rights and information security in the form of passwords authorizing access to specific files. Besides, it offers many functions designed to ensure the accuracy of data compliance, namely:

- the ability to save changed data,
- password identification requirements before making any changes to data,
- automatic blocking of data while making changes to them,
- data security,
- the output of saved data as a text file,
- exchange of graphic and descriptive data with other SICAD users and other systems,
- blocking certain files to modify them,
- automatic verification of data accuracy and compliance,
- comprehensive tests and correction functions.

## 4. Technical conditions of the geographical information systems implementation

As a rule, there is a Documentation Department in every power company. Its purpose is to collect, process and share documentation of HV, MV, LV networks or fiber optical networks for operational and planning purposes. The collection of documentation used to consist of appropriate organization and operation of a data archiving system, created using the traditional method in the form of maps and diagrams drawn on paper, and descriptive data also on paper. This collective inventory of electrical power equipment has not been and is not efficient because there is no connection between all this information. Due to the high density of objects on geodetic maps, the usefulness of these maps when conducting detailed network operational documentation, as well as in planning and management processes, was rather low. GIS systems introduce a new quality in this field, making a significant breakthrough in the area of resource information efficiency, integration possibilities and spatial location of data [21].

However, many technical problems and technical and organizational conditions are associated with the process of introducing geographical spatial information systems in the power industry. For example, when the transmission system operator or power plant decides to implement the system, he should be aware that this is a long and costly process that requires the appropriate distribution of activities over time, selection of appropriate software and equipment. One of the first choices that an investor should make is the choice of appropriate software that will meet all expectations placed in the introduced geographical information system. Then one need to decide how to implement the project, which is based on processing data from the archive to a numerical form. This task can be performed based on its own, properly trained employees, or it can be outsourced to an external company dealing with the creation of GIS systems.

The Geographical Spatial Information System usually consists of the following thematic layers, such as:

- detailed situational plan
- detailed plan of the utility network,
- the division into situational plans sheets,
- overview power line plan,
- an overview administrative division plan.

Creating the above layers requires completing all necessary information about the area covered by the system. A detailed situational plan is created by digitizing large-scale surveying maps (basic and reference maps in scales from 1: 500 to 1: 5000). The detailed situational plan consists of documentation regarding:

- presentation of borders and numbering of registration plots with their assignment to the appropriate geodetic precinct and administrative divisions of the country,
- presenting the course of land-use boundaries,
- presentation of buildings, roads, and other technical infrastructure facilities,
- presentations of selected elements of relief.

For the cadastral parcels, one can get information about the owner of the property.

The detailed utility network plan consists of documentation regarding:

- presentation of the power line is the subject of the study,
- presenting the course of other utility networks within the development zone.

The information in question should be transferred from files from the archive together with descriptive data regarding, e.g. network type, type of network, the numbering of columns, etc. However, the information available is not always current, so it should be verified with the current state. The division into situational plans sheets enables subsequent convenient printing of desired data and searching for it. Descriptive information about a given section of the line is assigned to each sheet, e.g. range of spans presented, units of administrative division within the scope of the sheet, timeliness of data.

When operations of processing information to the numerical form of the GIS system are performed by employees of the Documentation Department, there is no need to verify the correctness of the mapping, which occurs, however, when the above activities are performed by an external company.

## 5. Selected tools supporting spatial information systems

The process of introducing GIS systems in the power industry should not be lengthy or too expensive. It involves the necessity of digitizing traditional surveying maps and applying the network infrastructure to them.

Often, archived power line plans are incomplete and not accurate, and therefore need updating. This involves field inspections, which slows down the inventory procedures. To prevent this, auxiliary tools are used that significantly accelerate the tedious inventory. For example the FLI-MAP system is such a tool, which simplifies and accelerates the creation of GIS systems[22]. FLI-MAP (Fast Laser Imaging and Mapping Airborne Platform) consists of a helicopter equipped with a scanning laser that can measure a length of over 225 km per day (Fig. 2), because flying at an altitude of (20-225) meters at a speed of (40 – 80) km/h the system locates an average of (10 – 20) points per $m^2$. This high point density ratio allows one to determine the exact and reliable position and height of devices, substations, columns and other objects in the scanned corridor. Besides, it is possible to detect cable overhangs, the technical condition of existing lines or to search the area for new lines [22].

**Fig.2.** Using helicopter equipped with a scanning laser

FLI-MAP integrates the kinematic GPS system, scanning laser and Inertial Integration System and digital image into a complete portable measuring platform. Thanks to the use of advanced kinematic GPS technology, the relative accuracy of (3-6)cm measurements (absolute: 7-10 cm) can be achieved regardless of environmental conditions or the lack of permission to enter any property . FLI-MAP is equipped with two (high-resolution cameras. One of the cameras is looking down records at the same time the same part of the terrain that the laser scans. Precise UTC is recorded with each frame of the film, which ensures an exact link to the laser data. Messages from the pilots and the system operator are recorded on the audio track of the tape for archiving and help in interpreting the image.

The accuracy of position determination in the FLI-MAP system is ensured by two GPS receivers placed on the helicopter and many GPS ground stations. OmniSTAR satellite receivers are used to help the helicopter pilot accurately navigate in real-time along a pre-determined route . The scanning laser is safe for human eyes, non-reflecting distance meter capable of taking measurements in the range of (15 – 225) meters. Each scanned image contains 200 ordered measurements. The scanning angle is 60 degrees, and therefore the width of the scanned terrain is almost equal to the height of the plane above the ground. Surgically, the laser scans 60 times per second, which gives 12,000 points per second. The FLIMAP system directs and guides the pilot along with an established flight plan, using a light panel to show a deviation from the course, both horizontal and vertical. The horizontal course is determined by the positioning and navigation system, and the vertical course - by the scanning laser. The computer, operating the system working in the air, are many connected, based on Intel technology PCs that provide control of data from the air and control and navigation. Measurements such as seemingly aligned GPS and phase media, real-time laser scan recordings are stored on data media. As the FLI-MAP system is modular, it can be mounted in various types of helicopters (or drones). For this reason, this system is divided into two main parts, namely a platform with sensors and a computer system. The platform is mounted to standard connection points outside the helicopter. This platform includes a laser, video camera and two specially designed booms on which GPS antennas are mounted. The computer kit contains all the devices needed for collecting and processing data, such as GPS and OmniSTAR receivers, recorders, computers and data storage devices. The computer system which located inside the helicopter is connected to the platform with sensors via a central core.

At the end of each day of data collection, the helicopter flight path is pre-processed, checked, and formatted into a special file with information about the platform setting. During the pre-processing, the data is checked in various ways to make sure that the readings are satisfactory and that there are no gaps in the measurements. Appropriate horizontal map projection, vertical model parameters and desired units are selected. Special software is used to convert exact vectors from all base stations to the helicopter. To calculate the X, Y, Z coordinates of GPS laser readings, platform and laser data, as well as extract useful information from this FLI-MAP data, use FLIP software upgrade (FLIP 7 as basic in previous years) . This specialized computer software combines a helicopter position and additional information with laser data and video image (see Fig.3). It ensures full compatibility with the CAD system. FLIP software, together with another program, VcrController, controls the VCR time code, which allows the user to coordinate video images with processed laser data in order to obtain a full multimedia presentation of the measured area. FLIP software is also helpful in viewing and verifying the video image, allowing to gather additional information from the high-resolution image. Visualization of almost 625,000 data points per kilometer can be done in several ways that allow quick and accurate interpretation, for example:

- height - the laser points will be displayed as a colored pattern and in such a way that objects and features that have vertical relief are easily noticeable,
- intensity - different materials can have different reflection intensities, so objects and features that have little or no vertical relief are easily interpreted by changing the intensity.

FLIP software uses several special filters to reduce the original data into a more workable set of points. Some of the filters included in the FLIP program are earth filter (referring to soil), cable filter, column filter, line filter. The above filters are used for thematic grouping of laser data and allow one to view and export each topic individually. Various three-dimensional programs can be used for further analysis of data such as earth, wires, and poles, which are used by engineering software called PLS-CADD, distributed by Power Line Systems, for analysis and design.

FLIP software shows laser data in various ways, allowing the user to obtain three-dimensional information about the position of any object or feature represented in the data. FLIP software supports single points and multi-segment polylines that can be defined as drawing objects and can contain an unlimited number of drawing objects. An unlimited number of layers can be defined and marked with own color. The software also allows to assign nongraphical information to graphic data. Each layer contains drawing objects that consist of points, polylines, or sets of points and polylines. Each object class can have its own, user-defined, unlimited set of attributes, which can have unlimited amounts of defined values. When the user selects a point on a given layer, a dialogue box with a database to fill appears, e.g. a table appears containing: "Column number", "Column type", "Insulator type", "Insulator configuration" etc. Predefined values for "Insulator type" such as "Ceramic", "Polymer", "Other" can be selected from the list of options [22].

Drawing objects and their attributes can be imported into FLIP software or exported to a three-dimensional program, using the AutoCAD DXF format or a simple, flexible user defined ASCII text format. An example of such software is PLS-CADD Power Line System for analyzing and designing transmission lines and Track Maintenance Management System produced by Optram for data for the efficient management of power lines. An example of using the FLIMAP system is the inventorying of approx. 1000 km of high-voltage lines in the Netherlands. Because long-span transmission lines are difficult to map using conventional methods (they are expensive and time-consuming), the decision was made to use the FLI-MAP laser altitude system. The decision to carry out measurements using the new technique resulted from the ability to provide final data quickly, as FLI-MAP was able to provide the needed initial data within a few days rather than months. The operation lasted no more than 5 days and resulted in measurements of 1000 km of high voltage lines obtained using of FLI-MAP.

The following data were required in this project:

- positions 3731 poles and 67 substations,
- height of each pole,
- additional attributes (pole and line number),
- longitudinal profile along the central line with two points per meter,
- a DXF file containing a profile containing the pole number drawn in the correct place in the profile.

Due to several startup problems arising from the fact that the above data was required for the first time, the entire process of digitizing the line was completed within four weeks.

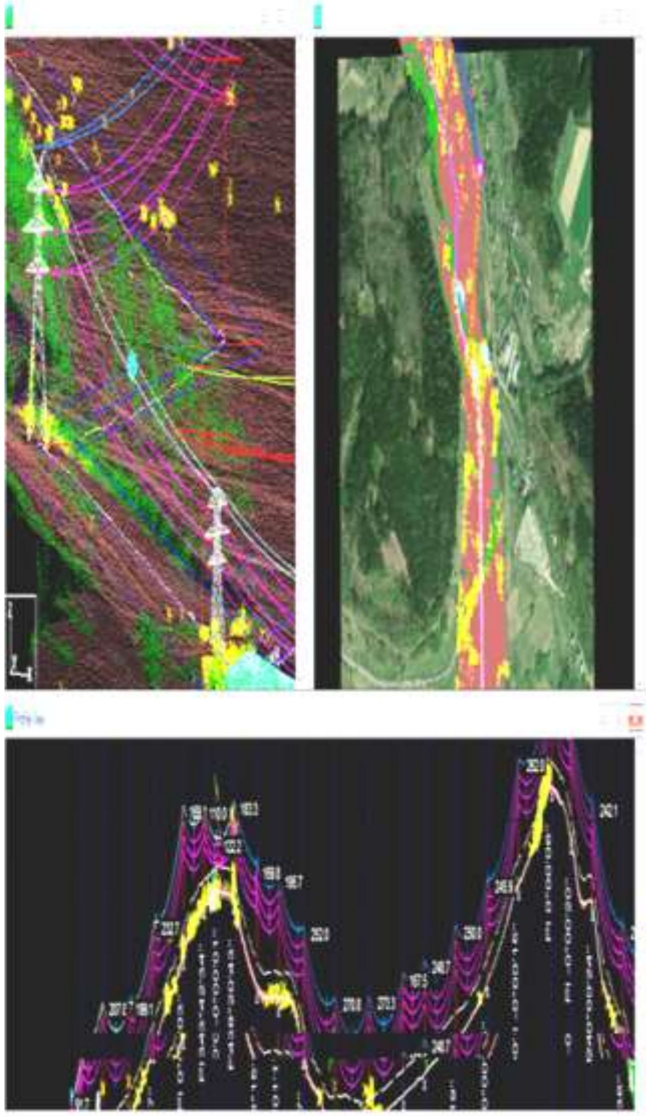

**Fig.3.** 3D visualization of laser data

The limitations of traditional corridor mapping techniques have disappeared using FLI-MAP because it provides a unique method for measuring long corridors by collecting accurate data in a precise, reliable, cost-effective, and fast way. Laser imaging and data scheduling, integrated with kinematic GPS and digital video, allowed Nuon to acquire valuable inventory of 1000 km of high voltage lines in a few weeks (instead of months) and with accuracy comparable to traditional measurement methods [23]. When using traditional measurement methods, it takes many years to collect the same data resource containing millions of {X, Y, Z} points, forming the longitudinal profile.

Even if the longitudinal profile consisted of one point per 100 meters (instead of two per meter), it would take several months to complete the measurements. Laser data and video from both cameras can provide information for applications, such as identifying objects (buildings, trees, etc.) etc.) that can threaten the power line and determine the overhang of existing cables.

The video image can also be used to determine the current situation during measurements, providing evidence in legal conflicts arising from illegal construction activities along the power line.

## 6. Forecasting the benefits of using information technology tools

For forecasting the benefits of using IT tools, the investment efficiency index "E" plays a key role in the calculations. This indicator consists of:

- sum of outlays and the accompanying sum of increase in operating costs after using IT tools,
- difference in annual costs of the enterprise before and after the application of IT tools supporting infrastructure management.

This can be represented by the following formula:

$$E = \frac{\Delta K}{\sum K} \tag{1}$$

where: ΔK - total expenses for IT tools; ΣK - difference of annual costs of the enterprise before and after applying the systems IT.

The sum of the expenditure and the associated operating costs can be represented by the formula:

$$\Sigma K = \Sigma K_i + \Sigma K_e \tag{2}$$

where: $\Sigma K_i$ - total expenses for IT tools, $\Sigma K_e$ - sum of costs related to the operation of devices.

The sum of costs related to the operation of devices may take positive or negative values (e.g. negative due to the liquidation of employees, reduction of fuel consumption for journeys related to the classic operation of the infrastructure, positive - employment of new qualified employees - IT specialists to take care of the system, etc.). The differences in annual costs of the enterprise can be presented using the formula:

$$\Delta K = K_{pm} - K_{mo} \tag{3}$$

where: $K_{pm}$ - annual costs of the enterprise before the introduction of IT tools, $K_{mo}$ - annual costs of the enterprise after the introduction of IT tools. The task of the economic entity is to maximize the objective function in the form of:

$$z = f\,(x_1, x_2, \ldots, x_n) \tag{4}$$

where the variables "x" express the resources needed to achieve the goal. In general, such a task will be to maximize the efficiency of the energy operation of the grid transmission company as a result of the introduction of modern IT systems for energy infrastructure management. This can be determined by the formula:

$$E = \frac{\Delta K}{\Sigma E} = f(x_1, x_2, K, x_n) \tag{5}$$

where: $(x_1, x_2, \ldots, x_n)$ - a set of features (input variables specific to a given object / enterprise).

The simplified assessment of the benefits of using IT tools should take into account the expenses determined depending on the size and structure of the power network. For example, using the work where the variable costs of maintenance were estimated, taking into account the costs of materials, equipment, wages and other components at approx. 19.6% of the annual total costs, the introduction of IT tools, in the author's opinion, would reduce the above costs by at least a few percentage points in on a yearly basis, which can represent a significant reduction in total annual costs[24].

In addition, the following additional benefits are obtained[24]:

- possibility of combining old and new technological devices into one monitoring and resource management system of power companies,
- reduction in the consumption of energy factors, better energy management,
- improvement of media quality and cost reduction,
- increasing the repeatability and efficiency of processes,
- greater reliability of transmission processes thanks to distributed control and central supervision,
- significant facilitations in monitoring / management of energy infrastructure.

## 7. CONCLUSIONS

According to the author, the introduction of modern IT tools will have a significant impact on the increase in efficiency (by reducing the operating costs) of transmission systems. It will also allow planning and programming of the rational development of the transmission company, taking into account market conditions.

Information systems and IT tools are increasingly determining not only the perception of the transmission system operators and power companies by customers, employees, partners, and investors but also perceptions of their products, services, and modes of operation. The appropriate calculation modules and procedures were introduced and possibility of data exchange with calculation programs.

One of the basic challenges facing the power industry is the need to integrate all elements of business operations in the IT system, which allows for a free transfer, processing, and presentation of data. To meet the needs of the moment, one should strive for a broad implementation of IT tools in the power industry.

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