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THE COMPUTING AND INFORMATION SYSTEM FOR RESEARCH OF PROSPECTIVE ELECTRIC POWER GRIDS EXPANSION

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Abstract: The paper describes the software tool implemented by Melentiev Energy Systems Institute SB RAS, aimed to solve wide range of energy issues. In this article, the Computing and Information System (CIS) means a software tool that provides collection, transfer, processing, storage, geo-visualization, and output of digital technical and economic data of different energy/power entities. Besides, this tool is incorporated within a mathematical model for optimization of expansion and operating modes of power systems. The paper discusses the example of how data storage and data representation in object-oriented database assist to improve efficiency of research prospective electric power systems expansion and operation.

Keywords: Geo-Information system, Optimization model, Data processing, Object-oriented database, Power plant, Electric power balance, Electric power system.

MSC: 68N19, 68P20, 68U35.

1. INTRODUCTION

The aim of our research is to develop a software tool to study prospective Interstate Power Grids (IPGs), particularly their economic effectiveness. A comprehensive study of transmission lines and electricity generation is necessary for the IPG system expansion and justification, see Tofael *e*t al. [18].

Therefore, we use an optimization model that allows us to study IPG expansion, choosing the optimal inputs of power plants and transmission lines (in model's nodes) to cover the growing load in the target year [6]. We collected and processed huge arrays of data for this model. However, most energy databases are not publicly available for research in this domain. We needed a special software with convenient user interface to work with the optimization model and to analyze the obtained results.

Many researchers and international organizations investigate the IPG formation. Among them: Global Energy Interconnection Development and Cooperation Organization (GEIDCO, China), Asia Pacific Energy Research Centre (APERC), United Nations Economic and Social Commission for Asia and the Pacific (UN ESCAP), Renewable Energy Institute (Japan) [14], Korea Electrotechnology Research Institute (South Korea) [17, 21], China Electric Power Planning and Engineering Institute (China), Economy and Technology Research Institute (China) [8] and others. A lot of universal and specialized software were developed. In most cases, relational databases are used for energy data storage. To process multidimensional data sets OLAP, Data Mining, and other methods are used. Such means of data storing and processing are intended for universal solutions but do not resolve the problems set before the authors.

Conditionally, the problems solved by using CIS can be divided into three groups given below.

1. The information-analytical problems:
   (a) storage of the energy data collected from various sources in a uniform structure;
   (b) data analysis over various time periods to reveal trends of electric power industry development, in particular, development of certain-type power sources, technologies of electric power generation, and use of various-type fuel;
   (c) the graphic and cartographic data representation.
2. The calculation-projection (computing) problems. To solve them we use our mathematical model for Optimization Power Systems Development and Modes (called ORIRES) developed at the Melentiev Energy Systems Institute. The purposes of their solution are:
   (a) assessing the effectiveness of interstate power grid development;
   (b) assessing the level of IPG integration and effectiveness;
   (c) optimization generating capacities, modes of energy power systems (EPSs) and IPG;
   (d) investigating EPS development in different countries.
3. Promotion and popularizing the investigation results to attract interest of the research community . Based on the CIS, we have developed the analytical Internet service (CIS web interface):

(a) to advance the idea of power integration among specialists of Russian and foreign energy corporations, as well as among all interested persons;
(b) to present (in a popular form) the investigation results on the Internet.

2. THE DATA PROCESSING AND GEO-INFORMATION COMPUTING SYSTEM

Currently, methods of processing and analysis of large amounts of data are studied by many researchers from different countries. In Russia, the well-known studies in the area of data processing were conducted by A.A. Barsegyan, M.S. Kupriyanov, V.V. Stepanenko and I.I. Holod – ”The Data Analysis Technologies. OLAP Data Mining” [4], V.A. Duke – ”Telemedicine”, ”Data Mining” [9]. The foreign reserachers involved in the study of information technologies for intellectual data processing (Data Mining) are Jiwei Han, Philip S. Yu (The Data Mining Group, University of Illinois, USA), Charu Aggarwal (IBM, USA) and others. The proposed methods of data processing are intended only for universal solutions but don’t meet the goals set. For a comprehensive study of the IPG extension and its justification, special data sets and data processing algorithms are required, taking into account the specifics of the subject area.

We solve various problems with laborious calculations to research the prospects and effectiveness of the IPG expansion. Herewith, the electric power systems (EPSs) are modeled as structurally complex energy entities that are described by a big set of diverse dynamically varying parameters. In the past, with no specialized software, the above problems were manually solved by labor-consuming calculations using the Microsoft Excel. For this reason, a specialized decision support system is necessary to examine the IPG system expansion and justification.

To the best of our knowledge, there are only several close functional software analogs. Those are the Asia Pacific Energy Portal by UN ESCAP [3], and the Energy GIS-system developed with the GEIDCO participation (China) [22], and APERC Energy Data Network Service [2]. All of them contain a considerable amount of data on power plants and transmission lines worldwide.

The above software analogs have no computing part, and in the context of this paper, will be termed only as information systems. We have been developing both the Computing and Information System in one software-product (called CIS). Our software, besides geo-visualizing the power data, is intended for experts in energy domain (our users) to conduct mathematical calculations and to construct well-substantiated projections for the IPG expansion by using the optimization Model [15]. The Model is unique and specially developed for optimizing the power systems expansion and their operating modes for the target (prediction) year.

[1]Decision Support System (DSS) in this context is an information system that supports business or organizational decision-making activities for experts.

The CIS is integrated with the General Algebraic Modeling System aimed at solving wide range of energy issues [7]. CIS includes several functional parts, see figure 1.

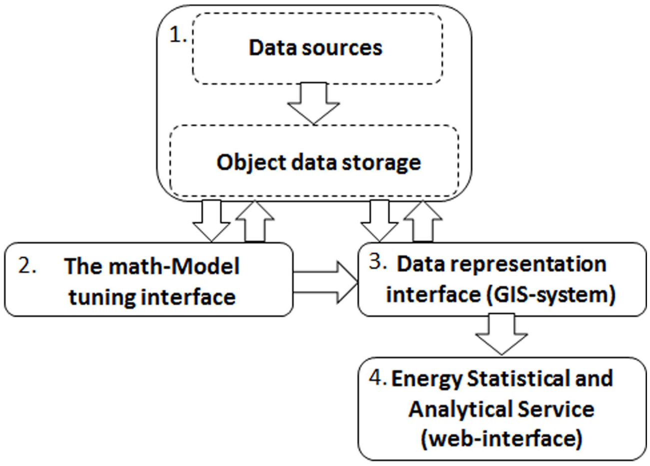

Figure 1: CIS functional parts

1. The purpose of ”data sources part” is to collect data from various information resources (energy databases, Internet, statistics etc.) and convert it to a uniform database structure used in CIS. To store the collected data in a uniform structure, we have developed the special Object-Oriented Database. The data represent a set of files in a special machine-readable format containing the parameters for each database object, its text, and numerical values with special separators.
2. The second functional part is intended to operate the ORIRES optimization model. The special user interface allows one to adjust and vary (tuning) the ORIRES input parameters, the number of nodes and constraints, to run GAMS optimizer and to generate the final set of tables with the optimal solution results. Further, the obtained set of tables determining a certain scenario of the IPG expansion for the target year is also stored in the CIS data structure.
3. To visually represent and analyze data from object-oriented database, we have developed the data representation (and geo-visualization) interface.

[2]The General Algebraic Modeling System (GAMS) is a high-level modeling system for mathematical optimization. GAMS is designed for modeling and solving linear, nonlinear, and mixed-integer optimization problems. The system is tailored for complex, large-scale modeling applications and allows users to build large maintainable models that can be adapted to new situations.

[3]The ORIRES model is an optimization, linear, static and multi-node one. It optimizes the volumes and the mix of generating capacities, the transfer capacity of transmission lines, the operating modes of power plants and flows among nodes (electric power systems), for the target year.

As a background, we use the maps built by Google Maps API, on which semi-transparent layers are imposed, representing various power parameters. This interface enables one to scale the map and to look through the trends of parameter variations over different time periods, for example, over the last 20 years. Users can look through these trends on the built maps, as well as in the form of charts or diagrams.

4. Further, we developed a special Energy Statistical and Analytical Service to represent the research results to the Internet. At a request, the CIS-generated maps, tables, and diagrams (keeping some dynamic functions implemented through web programming) are exported into this web interface.

The routine work of the CIS users comprises of several stages. At the preliminary stage, researchers directly search often non-systematized data at various Internet resources. This stage is the most labor-consuming in terms of using human resources. Further, the found data is analyzed in CIS through special program algorithms for compliance with semantic templates (sets of certain-type objects and their parameters) in database structure. If necessary, the templates are edited or new ones are formed (corresponding to the new type of objects).

Herewith, the general structure of database does not vary: only the set of objects, their parameters with values, and the relations between objects may be changed. Objects in CIS database may be power plants, transmission lines, energy power systems, as well as countries (power grid at the country's level). Next, there comes automatic data loading to the database object-structure. To each new type of objects, this operation occurs only once. In case, when there is updated information on the objects existing in the database (for example, new statistics for the current year), then a special algorithm automatically distributes new values to the corresponding cells in the database objects structure.

At the next stage, CIS user, a researcher-expert dealing with design diagrams and IPG development projections by using the ORIRES mathematical model works. For this purpose, a special user interface is run in the CIS. There, the expert can tune various model parameters, specify the design diagram with a set of nods, and run the built-in optimizer. Many parameters displayed in this interface are taken from the corresponding objects of the database, for example, installed capacities of power plants or the cost of a certain type of fuel in a country, etc.

At the optimizer's output, there are forms of a set of tables with optimal values of the IPG parameters for the target year (economic, technical, and other) obtained as a result of solving the ORIRES optimization problem.

Further, the obtained solutions in a tabular form are used in the CIS. For example, export to the Microsoft Excel for further work with tables, or presentation of separate selected parameters in the CIS graphical interface to build interactive maps, plots, and diagrams, in order to analyze the data retrospectively and prospectively. In addition, user can export the processed data to our independent analytical Internet service, for disseminating the research results among the world scientific community.

3. THE OBJECT-ORIENTED DATABASE

In this paper, we offer a new approach to organize data storage by using special object-oriented database (OODB). The database is original and specifically developed by the authors for the needs of this project. The OODB contains an object file structure and metadata describing the levels and relationships between database objects. We have developed special software algorithms to work with the OODB structure. Each database object describes the properties of real world power entities (power plants, energy power systems, power grid at the countries, etc.). OODB object represents a record containing the object unique identifier, the set of the parameters describing it, and the values of each parameter in the text or numerical form, stored by years, months, days, hours, etc. Any text editor can be used to view OODB files system format [19].

The content of database objects is represented in CIS interface by dynamic editable tables. The table contains object parameters and its values, see Table 1. The edited values are automatically recorded to object format.

Further, a separate file is opened in a simple text editor, where user can see a fragment of parameters and the values of the selected object, written in a special format. In the example above, there is a fragment of the data for the South Korea EPS object. Here we can see:

A) Text parameters of the object – the unique identifier (*ID*), object name (*name*), belonging to a certain region (*ch_REG*) and maybe other;

B) Numerical parameters – maximum load of consumers in this EPS (*max_load*, in MW per year); consumers load for every hour, normalized to 1 (*ww_r*, *wh_r*, *fw_r*, *fh_r*, *sw_r*, *sh_r*, *hw_r*, *hh_r*), where *ww* – weekdays in winter, *wh* – holydays in winter and the same in spring, summer and autumn); types of power capacities (power plant types) in this EPS (*type_st*); a set of constrains (see below 5 about the optimization model used) for each capacity type t_{1-8} and other object's parameters. This list of parameters is length unlimited and may occupy several pages. The inner structure of OODB files is not only convenient for machine processing, but also is clear to a person (human). The data structure universality and simplicity makes them practically independent of the medium/system program part and processing algorithms. It takes little effort to read this structure and make new processing algorithms in other programming language, for example, when creating the CIS web interface. In addition, it is not necessary to create a set of auxiliary tables and indexes (as in most relational databases).

Name	Values				
ID	46878432167Korea__South				
name	Korea, South				
ch_REG	NEA				
Hour	1	2	3	...	24
max_load	122910				
ww_r	0,91	0,915	0,91	...	0,88
wh_r	0,704	0,711	0,71	...	0,705
fw_r	0,873	0,89	0,891	...	0,85
fh_r	0,727	0,728	0,729	...	0,721
sw_r	0,913	0,948	0,972	...	0,822
sh_r	0,854	0,874	0,872	...	0,788
hw_r	0,891	0,923	0,945	...	0,822
hh_r	0,669	0,686	0,701	...	0,666
type_st	Hydro_PP=t1, Pumped_Storage_PP=t2, ..., Thermal_PP_Coal=t5, Thermal_PP_Gas=t6, Thermal_PP_Oil=t7, Nuclear_PP=t8				

t1	wa=0.1<0.1<0.9;fa=0.1<0.1<0.9;
	 sa=0.1<0.1<0.9;ha=0.1<0.1<0.9;
	 no=1.79;nm=1.9;;kap=2520;b1=0.02;rr=0.08;				

t2	wa=0<0<0.9;fa=0<0<0.9;
	 sa=0<0<0.9;ha=0<0<0.9;
	 no=4.7;nm=4.7;;kap=980;b1=0.033;rr=0.08;				

...					

t5	wa=0.5<0.5<0.85;fa=0.55<0.55<0.85;
	 sa=0.55<0.55<0.9;ha=0.4<0.35<0.85;
	 no=44.394;nm=57.1;cex=0.038;kap=1390;b1=0.055;rr=0.08;				

t6	wa=0.37<0.37<0.85;fa=0.37<0.37<0.85;
	 sa=0.37<0.37<0.9;ha=0.37<0.37<0.85;
	 no=33.594;nm=35.2;cex=0.14;kap=840;b1=0.05;rr=0.08;				

t7	wa=0.47<0.47<0.85;fa=0.47<0.47<0.85;
	 sa=0.47<0.47<0.9;ha=0.47<0.3<0.85;
	 no=1;nm=1;cex=0.23;kap=1900;b1=0.05;rr=0.08;				

t8	wa=0.8<0.8<0.9;fa=0.8<0.8<0.9;
	 sa=0.8<0.8<0.9;ha=0.8<0.8<0.9;
	 no=30.16;nm=44;cex=0.008;kap=2350;b1=0.12;rr=0.08;				

Table 1: A fragment of data on the selected OODB's object.

Object-data representation allows user to compactly store large data of different object types, data collected for different points and frames of time, and from any source. Special data processing algorithms include the methods for object verification, interpolating of missing data, mathematical formulas for converting and combining various parameters. Our experience with various databases shows that such algorithms are rather difficult to implement in standard SQL queries. Presented at the figure 2 is an OODB flowchart.

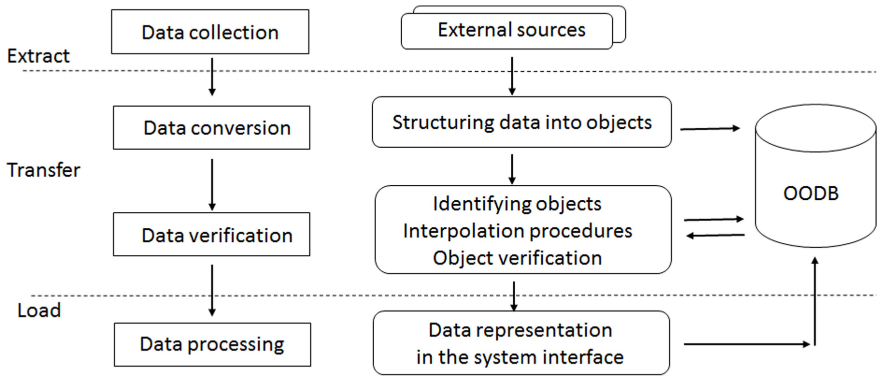

Figure 2: OODB flowchart

The data storage technology, like the one object form, has an advantage over relational databases for the following reasons:

- The record number and length in our data structure are not limited. Accordingly, one can store an infinite number of the object certain parameter output values in one string, for example, hourly load within an entire year or period of years without creating additional relational tables.

- One may use a free type/format of parameter values, viz., fractional, integer, or text, stored in an unlimited range of values. For example, frequent change in the names of energy/power entities by years can be presented in the form of the Name parameter, whose text values are written in one string with special separators. The values for such a parameter can be taken from OODB for any requested year, or for several years, for example, to see the name change trend.

- A little number of relational tables and indices in case of operation with big lists of different-kind energy/power entities.

- Compactly presented full data on the energy/power entity in a single file of a special format. This representation provides confidence in the integrity of the data and eliminates the potential loss and data that occurs in complex SQL queries that ”collect” values for one or more entities from different relational tables. We have developed special user interface of CIS for data input/output from OODB by using graphic and cartographic data presentation. Also we developed program algorithms to verify the data and check it for integrity.

4. THE GRAPHICAL DATA REPRESENTATION EXAMPLE

We have considered the energy balance statistics distributed by the International Energy Agency (IEA) [12]. Information provided by the IEA contains retrospective data of energy balances of almost all countries in the world (more than 200 countries), starting from the 1970s. A multidimensional cube (OLAP-data representation) represents the data, see figure 3.

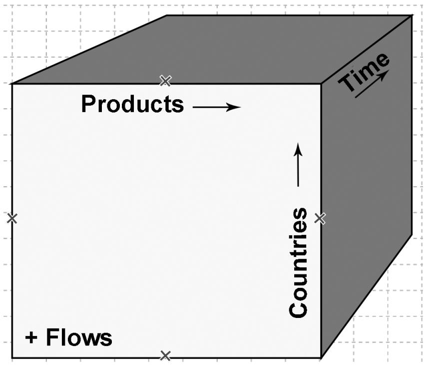

Figure 3: Multidimensional data cube for energy balances of countries

One of cube sections is energy balance of the country, for any year. Access to this data is possible only through a special application that allows users to view slices of this cube. Data processing is limited by the application capabilities. In addition, to study electric power systems, it is necessary to choose only the electric component from a huge array of data.

CIS allows us to collect and restructure input data into the object-oriented storage. The entire volume of the above information was transferred into OODB. It was about 200 objects in OODB (by number of countries) with energy objects indicators. We have developed special cartographic unit to make interactive maps with energy objects indicators both for retrospective data and for calculated prospective.

The indicators display as pie charts on the map, for any region in the world. These maps are created in automatic mode in CIS and we can view indicators changes for different years. In addition, there is a mode of exporting constructed maps to a special Web application [20]. For example, the map shows electricity consumption for all countries in the world, see figure 4. Electricity consumption is given in *TWh* – Terawatt hour. Sizes of pie charts are proportional to the amount of electricity consumed.

To conduct quality research, we should have maximal comprehensive information on the investigated entities or processes. In particular, to determine the current state of energy power system in a region, it is necessary to have the whole information on the installed generating capabilities of this EPS. The "Data sources functional part" of the CIS is universal to collect data from various data resources

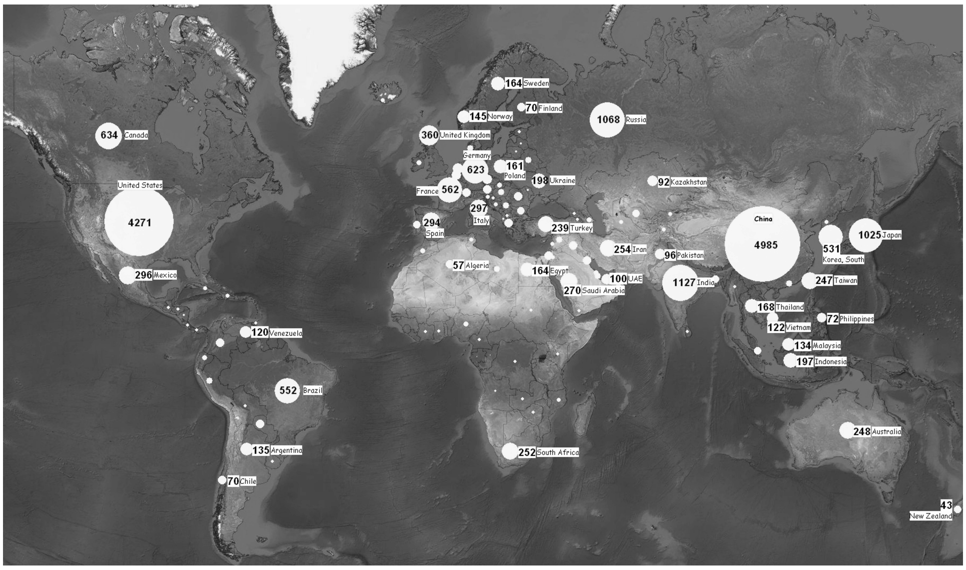

Figure 4: World electricity consumption (TWh per year)

– not only from IEA. It implements data processing algorithms using semantic compare of information on the specified patterns (lists of energy entities and its parameters corresponding to the object data structure). To work with data obtained (downloaded) from "energy" Internet resources, such as Global Energy [11], EniPedia Portal [10] and others, we have developed special verification algorithms – checks for data integrity (with filling in missing fields), prevention of object duplication (indexing of unique objects) etc.

Actually, the certain algorithm for loading and converting the information into the OODB depends on certain type of data sources. Because of the developed algorithms for various sources, we form and enlarge the OODB with unique information collected in a uniform structure, whose usage expands manifold possibilities and upgrades the quality of our scientific research. Further processing the data from the OODB is performed through a special query designer. So users do not depend on programmers, and they do not need specialized knowledge to construct complex SQL queries. The "query designer" allows users to generate comprehensive and parametrized queries, contains special calculations, such as linear interpolation of missing data, and other mathematical data transformations (addition, subtraction, multiplication, division, etc.).

The "query designer" enables to extract object parameters, classify the latter, sample, and aggregate. In particular, for power plants, we added the parameters for their cartographical binding and possibility of presentation on the CIS cartographic interface see above. With the knowledge of the exact location of energy entities, users can aggregate the data at various levels, which opens possibilities to scale the design scheme (EPSs power grid). We can aggregate the collected information by various countries, regions, national power systems or their subsystems.

The cartographic interface allows users to make EPSs maps with coordinates, connections, volumes, capacity types and others. CIS also allows us to make the forecast of these indicators for the target year.

5. THE OPTIMIZATION MODEL

The ORIRES mathematical model for optimization of the power system expansion and operating modes (thereinafter - the Model) is used when calculating various prospective scenarios for creation of interstate power grids and optimal expansion and operation of interconnected power systems [5]. Herewith, we considered capital investments, fuel costs, annual operation and maintenance costs, and presented the variables featuring the installed capacities and actual power of different-type power plants, transfer capabilities of transmission lines, etc. The Model enables one to simultaneously optimize several interconnected EPSs and transmission lines among them. The Model is linear, which is permissible, considering a long-term character of the resolved problems and significant capacity of modelled power systems. The Model is also multi-nodal, which enables one to consider the territorial distribution of EPSs and IPGs. We accept regional, interconnected, or national EPSs as the design diagram nodes. Investigations with the Model are conducted for the assumed prospective target year (for example, 2035).

The Model objective function is to reduce the IPG costs in general to an annual dimension. They include specific fuel costs for electric power production by various-type power plants, costs for commissioning new capacities and their maintenance (investment and operation component, that are correlated with research in this subject area) [13] [1], and cost of commissioning new transmission lines, connections (tie lines) among nodes. The optimal solution is determined by minimal costs (1), when meeting the loads at all the nodes of the design diagram.

Objective function.

$$\sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{y=1}^{Y}\sum_{t_y=1}^{T_y} c_{ij}\tau_{t_y}x_{ijt_y} + \sum_{j=1}^{J}\sum_{i=1}^{I} k_{ij}(r_j + b_{ij})X_{ij} + \\ + \sum_{j=1}^{J}\sum_{\substack{j'=2 \\ j'>j}}^{J} k_{jj'}(r_j + b_{jj'})X_{jj'} \to min \quad (1)$$

$j, j' = 1, \ldots, J-$ number of nodes in the interconnected EPSs (J - their total number for all EPSs);

$i = 1, \ldots, I_j-$ number of power plant types in node j (all plants of the same type in the node are represented as an equivalent power plant of total installed capacity with averaged technical and economic indices);

$y = 1, \dots, Y$– number of seasons within a year (usually four seasons – winter, spring, summer and autumn);

$t_y = 1, \dots, T_y$– number of hours of a working day and a holiday in season y (hours $t_y = 1, \dots, 24$ correspond to a working day and $t_y = 25, \dots, 48$ - to a holiday);

c_{ij}– specific fuel costs of power plant i in node j (USD/kWh);

τ_{t_y}– number of working days or holidays in season y;

x_{ijt_y}– actual power of power plant i in node j at hour t_y (kW);

k_{ij}– specific investments in the new or expanded power plant i in node j (USD/kW);

$k_{jj'}$– specific investments in the tie line between nodes j and j' (USD/kW);

r– rate of return;

b_{ij}– fixed costs of power plant i in node j as a fraction of specific investments;

$b_{jj'}$– fixed costs of the tie line from node j to j';

X_{ij}– installed capacity of power plant i in node j;

$X_{jj'}$– transmission capacity of the tie line between nodes j and j' by the target year (kW).

Balance equations.

The objective function is to optimize within certain set of constraints, including balance ones. For example, the power generation (considering export and import) should not exceed the set load at the node; the installed capacity for the target year should be within the indicated limits for each type of power plant, and so on. All indicated parameters of the Model are customized through the CIS special interface.

Balances of installed capacities of power plants for hours of load maxima:

$$\sum_{i=1}^{I} X_{ij} - \sum_{\substack{j'=1 \\ j'\neq j}}^{J} x_{jj't_y} + \sum_{\substack{j'=1 \\ j'\neq j}}^{J} x_{j'jt_y}(1 - \pi_{j'j}) \geq P_{jt_y} + R_{jt_y} \tag{2}$$

$j = 1, \dots, J; t_y \in T_y^{\max}; y \in Y^{\max}$

X_{ij}– installed capacity of power plant i in node j;

$x_{jj't_y}$– power flow from node j to node j' at hour t_y (kW);

$\pi_{jj'}$– loss factor while transmitting power between nodes j and j';

P_{jt_y}– consumers load in node j at hour t_y (kW);

R_{jt_y}– required capacity reserve at power plants in node$j$ at hour t_y (kW);

$T_y^{\max}$– set of hours with annual load maxima of EPSs being interconnected;

$Y^{\max}$– set of seasons in which these load maxima take place.

Balances of power in each node j for each hour t_y of season y:

$$\sum_{i=1}^{I} x_{ijt_y} - \sum_{\substack{j'=1 \\ j'\neq j}}^{J} x_{jj't_y} + \sum_{\substack{j'=1 \\ j'\neq j}}^{J} x_{j'jt_y}(1 - \pi_{j'j}) = P_{jt_y} + x_{jt_y}^{char} \tag{3}$$

$j = 1, \dots, J; t_y = 1, \dots, T_y; y = 1, \dots, 4$

x_{ijt_y} – actual power of power plant i in node j at hour t_y (kW);
$x_{jj't_y}$ – power flow from node j to node j' at hour t_y (kW);
$x^{char}_{jt_y}$ – charge capacity of pumped storage power plant (PSPP) in node j at hour t_y (kW).

Constraints.

- On expansion of power plants:

$$N^0_{ij} \le X_{ij} \le N^M_{ij} \tag{4}$$

$$i = 1, \dots, I_j; j = 1, \dots J$$

N^0_{ij} – installed capacity of existing power plants of type i in node j in the target year (kW);
N^M_{ij} – maximum possible installed capacity of power plants of type i in node j in the target year (kW).

- On expansion of tie lines:

$$C^0_{jj'} \le X_{jj'} \le C^M_{jj'} \tag{5}$$

$$j = 1, \dots, J; j' = 2, \dots, J; j' > j$$

$C^0_{jj'}$ – initial (existing) transmission capacity of the tie line between nodes j and j' (kW);
$C^M_{jj'}$ – maximum possible transmission capacity of the tie line in the target year (kW).

- On actual power of power plants:

$$a^m_{ijy} X_{ij} \le x_{ijt_y} \le a_{ijy} X_{ij} \tag{6}$$

$$i = 1, \dots, I_j; j = 1, \dots J; t_y = 1, \dots, T_y; y = 1, \dots, 4$$

a^m_{ijy} – index of minimum admissible capacity of power plants of type i in node j in season y (as a fraction of their installed capacity);
a_{ijy} – availability index of power plants of type i in node j in season y (as a fraction of their installed capacity).

- On power flows via tie lines:

$$C^m_{jj'y} \le x_{jj't_y} \le X_{jj'} \tag{7}$$

$$j = 1, \dots, J; j' = 1, \dots, J; j' \ne j; t_y = 1, \dots, T_y; y = 1, \dots, 4$$

$x_{jj't_y}$ – power flow from node j to node j' at hour t_y (kW);
$C^m_{jj'y}$ – minimum admissible loading of the tie line between nodes j and j' in season y (kW);
$X_{jj'}$ – transmission capacity of the tie line between nodes j and j' by the target year (kW).

In addition, in the Model there are integral constrains on the operation of HPPs (hydro power plants) and PSPPs: in particular, on charge capacities of PSPP, on the total electricity generation by HPP, on daily balances of charge and discharge energies of PSPP, and on their available water storage.

Optimized variables of the Model are X_{ij} , $X_{jj'}$, x_{ijt_y} , $x_{jj't_y}$, $x_{j'jt_y}$, $x^{char}_{jt_y}$.

Non-zero differences $(X_{ij} - N^0_{ij})$ or $(X_{jj'} - C^0_{jj'})$ in an optimal solution of the Model will indicate the effectiveness of corresponding power plants or ISETs. Actually these differences should be in objective function (1) instead of variables X_{ij} and $X_{jj'}$ but the constants N^0_{ij} and $C^0_{jj'}$ will not influence a solution.

Values of the variables x_{ijt_y} and $x_{jj't_y}$ will characterize the operation of EPSs and ISETs in the corresponding seasons and days. The value of the first component of the objective function (with four sums) will show the total fuel costs in all interconnected EPSs (or in entire interstate power interconnection).

6. RESULTS EXAMPLE OF THE MODEL'S SOLUTION

The Model ORIRES uses the general algebraic modeling system that is run from the CIS interface, reads the Model parameters set in the special interface, and forms the optimal solution at the output (like a set of tables with the optimized values for the Model parameters). The CIS graphic interface enables one to visually assess and interpret the selected options on maps, graphs, as well as to build spreadsheets.

Volume matrixes of primary detailed output data are converted into aggregated table templates with results. As an example, we exhibit the aggregated tables with prepared results of optimizing the expansion of power systems of the North-East Asia countries for 2035 [16]. Table 2 provides the electricity flows among nodes. Table 3 presents the structure of power generation mix for various-type power plants.

No	Power system (node)	Power generation, TWh	Pumped storage charge, TWh	Output (export), TWh	Inflow (import), TWh	Total consumption, TWh
1	East (Russia)	87,7	0	-114,2	99,4	72,9
2	Siberia (Russia)	408	0	-70,4	0	337,6
3	Sakhalin (Russia)	7,5	0	-64,8	63,3	6
4	Japan	1070,3	-19,3	-3,1	137,9	1185,8
5	North Korea	106,1	0	-92,8	67,1	80,4
6	South Korea	848,5	-4	-85,6	86,1	845
7	Mongolia	23,2	0	-2,4	0,9	21,7
8	Northern China	2969,7	-8,2	-61,4	6,8	2906,9
9	North-East China	1131	-5,5	-80,1	95,6	1141

Table 2: Electricity flows among nodes (terawatt hours per year)

No	Power system (node)	Thermal			Nuclear, TWh	Hydro, TWh	Pumped storage, TWh	Wind, TWh	Solar, TWh	Power generation, TWh
		Coal, TWh	Gas, TWh	Oil, TWh						
1	East (Russia)	31,2	13,5	0	0	43	0	0	0	87,7
2	Siberia (Russia)	168,8	9	17,8	0	212,4	0	0	0	408
3	Sakhalin (Russia)	2,4	5,1	0	0	0	0	0	0	7,5
4	Japan	233,8	199,5	266,8	123,2	167,2	15,5	19,7	44,5	1070,2
5	North Korea	19,1	27,1	0	4,1	53,5	0	1,2	1,2	106,2
6	South Korea	306,7	138,3	326,9	3,8	14,1	3,2	42,2	13,2	848,4
7	Mongolia	17,9	0	0	0	4,1	0	1	0,2	23,2
8	Northern China	2682,3	60,7	85,9	0	23,8	6,6	70,9	39,5	2969,7
9	North-East China	986,8	1,7	24,1	0	50,3	4,4	52	11,7	1131
	Total	4449	454,9	721,5	131,1	568,4	29,7	187	110,3	6651,9

Table 3: Power generation mix by various-type power plants (terawatt hours per year)

The aggregated forms of tables containing some results of computations for 2035 by using the ORIRES optimization model generated in this example are clear and convenient for experts to analyze.

The CIS is multiply increases the performance of the data processing. Earlier, the results of the Model were calculated ”manually” by using the Microsoft Excel. The Model calculates the optimal load of the EPS for each hour (24 hours a day), for weekends and holidays, and for 4 different seasons. In total, 192 equations are optimized simultaneously for each capacity type mix. All parameter values are stored in the OODB. Previously, calculations were performed using macros that were supposed to process multiple Excel tables. One calculation took about 40 minutes. But the longest process was the input / change parameter values in large Excel tables. This problem could take a lot of time, about a month.

Now, the CIS interface for setting / changing parameters allows the user to immediately work with summary compact data spreadsheets and enter new parameters for each node (EPS) within a few hours (if the necessary data is available). One calculation by using the CIS takes about 40 seconds.

The CIS considerably simplifies creating such tables, promotes reducing labor-costs when searching, checking, and forming the parameters for the optimization Model, helps to visually represent the results of the obtained calculations in graphic and cartographic form, rising the research quality.

7. CONCLUSION

Among constantly changing databases and information systems offered on the market, there are specialized decision support systems, especially in case when it is necessary to have a compact data structure and transparently store information. In this case, the procedures for extracting, processing and data visualizing must have a universal interfaces that can be customized for various issues related to research prospective electric power systems.

We propose a new, modern approach to analyze and process a large volume of data. The main components (program modules) of CIS related to solving problems of power systems expansion have been developed.

The data storing technique based on object-oriented database, and data processing by graphical interfaces of CIS, considered in this paper, are universal and may be applied to help in solving many energy issues. The proposed technique greatly simplifies calculations, and reduces time for making forecasts of interstate power grid expansion.

CIS is a kind of decision support system, intended to improve research efficiency of prospective electric power systems expansion and the quality of optimization models solutions by using convenient interfaces.

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