Technical Features of the Computing and Geo-Information System for Research of Prospective Interstate Power Grid Expansion

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***Abstract*—The purpose of this paper is to present opportunities and technical features of the developed software for study of prospective Interstate Power Grid (ISPG) expansion in Northeast Asia. The mathematical model for optimization of power systems expansion and operating modes, which is the main part of the computing & geo-information system (CIS), is used. In this model, a linear optimization method is used to find optimal installed capacities by generation type mix; optimal electric ties transfer capabilities and operating modes for each electric power system in the ISPG. Annualized costs of the ISPG expansion as a whole are the value of the objective function. The obtained results of the model in tabular, graphic and cartographic forms are presented. Examples of the CIS usage for study of different scenarios of ISPG expansion in the Northeast Asia are shown.**

***Index Terms*—Interstate power grid, power grid optimization, computing system, geo-information system, optimization model, data processing, object database, power plants, energy power system**

I. Introduction

Electricity integration is a global process affecting many regions around the world. Comprehensive research of the prospective Interstate Power Grids (ISPG) expansion is required on the pre-project stage. Sophisticated optimization methods and models are used around the world to justify economic efficiency and technical feasibility of interstate and national power grids expansion. International experience shows that electric power integration is cost-effective for the parties involved. The ISPGs have been developing in North and South America, Africa, Europe and Asia. Many studies of prospective ISPG in Northeast Asia (NEA) are being conducted [1]-[4]. It is important to perform a comprehensive analysis of technical, economical, and environmental issues of ISPG expansion. Problem-oriented software with energy database is needed to increase the efficiency and research quality.

The largest energy hub in NEA region is China – the world leader in electricity production and consumption. The creation of ISPG in NEA solves many problems, associated particularly with a high level of CO_2 emissions, interstate electricity redistribution at peak loads, an increase dominance of renewable energy sources in regional energy balance etc.

Many scientists, institutes, international and intergovernmental organizations are involved in the research of the ISPG expansion in Northeast Asia: the Renewable Energy Institute (Japan) [5], China Electric Power Planning & Engineering Institute (China), Global Energy Interconnection Research Institute (China) [6], University of Malaya (Malaysia) [7], [8], Korea Electro-technology Research Institute (South Korea) [9], [10], Asia Pacific Energy Research Centre (APERC), United Nations Economic and Social Commission for Asia and the Pacific (UN ESCAP) [11], [12], Global Energy Interconnection Development and Cooperation Organization (GEIDCO) [13], and others. In Russia, the Melentiev Energy Systems Institute of Siberian Branch of the Russian Academy of Sciences and Skolkovo Institute of Science and Technology are involved into this research. In the Melentiev Energy Systems Institute, it is used the mathematical model for Optimization of Power Systems Expansion and Operating Modes (called ORIRES, further – the Model).

II. Optimization Model

The Model is used to study different scenarios of ISPG expansion for prospective target year. In this model, a linear optimization method is used to find a solution, which determines the optimal installed capacity and generation type mix of the considered power systems; the interstate electric ties transfer capabilities, and the operating modes of these capacities and ties. Electric power system (EPS) is represented in the model by its own power generating capacities, both current and potential ones, aggregated by type of power plants [14].

Power demand of EPS consumers is characterized by a graph of daily electrical load, which determines how much electricity needs to generate for each hour. The problem of determining the actual power for each type of power plants is considered in the modeled EPSs, taking into account the electricity transfer between these systems.

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The objective function includes the total annual fuel costs of electricity by generation type, annualized investment costs of new capacities and new electric ties, and annual maintenance cost. The objective function is optimized within set of constraints (on expansion of capacities, electric ties, actual power etc.) and two types of balance equations: balance of installed capacities in the hours of yearly load maxima and balance of actual power (for each operating hour).

The minimum value of objective function (minimum annualized costs) is the optimal solution of the Model, when obtained are the optimal capacity and generation mixes in each EPS, its optimal operating modes at each hour (for weekdays/weekends) and for different year seasons (winter/spring/summer/fall).

A distinctive feature of this model unlike analogues (which basically solve the transport problem of redistributing electricity between nodes) is that the ORIRES model optimizes installed capacities and electricity ties taking into account daily/hourly electrical load in each node.

III. Software Operation Algorithm/Technology

The processing, visualization and analysis of the huge amount of complex data requires the special software for data management and presentation. The authors have developed the Computing & Geo-Information System (CIS) with integrated optimization model concisely considered above [15]. The CIS allows one to enter, configure and change parameters of the Model; run the computations (the optimal solution finding); create and store results in the original energy/power database; display the computing results in easy-to-understand forms.

The CIS Database is based on the object-oriented file structure for storing and presenting energy/power data. Power plants with their parameters, power systems, electric ties, countries and different regions can be objects of the database. Database objects contain geographical information for the implementation of visual presentation and qualitative analysis; information on the relationships between objects, their regional affiliation; technical and economic data reflecting various parameters of energy/power objects/entities. Currently, the Object-Oriented Energy Database (OODB) has been designed and implemented [16].

CIS software engine is based on the Embarcadero Delphi. Design of the OODB file structure and data access interface is unique and developed by the authors. The data query, browse, extraction and other operations are supported. According to acquisition of various data types from various sources, the corresponding data conversion algorithms are constructed. It is used geospatial data for constructing maps with grid scheme of ISPG. The software implementation of the mathematical model ORIRES is the main part of the CIS. It is used the General Algebraic Modeling System for solving linear programming problem (LP-optimizer) [17]. All model parameters and data are configured through interactive CIS interface.

Main features of the CIS interface for working with the Model:

- Making changes to the mathematical equations written in the LP-optimizer language;
- Enable/disable model constraints;
- Operational tuning/editing of input parameters for the model;
- Creating, turning on/off model nodes (EPSs on the design scheme of the ISPG);
- Creation of inherited scenarios (scenarios tree), their storage in OODB and comparison;
- Control and analysis of input parameters of the model (admissible to given constraints).

The CIS operation algorithm/technology is described below:

1) The operator (CIS user) configures the parameters for starting the model (creates the initial model configuration). All model parameters for the corresponding scenario/variant are stored in the CIS database.

2) Then starts the LP-optimizer, which can “reads” the specified model parameters.

3) Numerical parameters are accordingly set in the equations and constraints of the model.

4) If all constraints are met, an optimal solution is formed at the exit from the process. It can be presented in tabular form with the optimal values of all model parameters.

5) If there is no solution (the parameters do not satisfy any model constraints), the CIS interface generates an error "solution incompatibility", and the operator (CIS user) is asked to change the initial configuration. After that, the computational process is considered done.

IV. Technical Features of the CIS Interface for Tuning Model Parameters

To configure the model in the CIS interface, special modules/blocks are provided:

- Interactive form for model nodes (EPSs) creating;
- Form of electric ties parameters;
- Interactive form for setting constraints by generation type mix for each node;
- Form for setting electric load graphs/profiles for the nodes by four seasons of the year, weekdays and holidays (eight profiles for each node);
- Form for management of the scenarios tree.

A. *One Node–the One Object in Database*

All exhaustive information about each EPS can be presented in tabular forms, Fig. 1. At the physical level, this data are stored in one file object in OODB. Each object represents as a file-record containing the unique identifier, the set of object parameters, and the values of each parameter in text or numerical form, which can be separated by year, day and hour (for parameters of electric load profile). Any text editor can be used to view OODB files system format. Object-data representation allows us compactly store complex data for different energy/power objects.

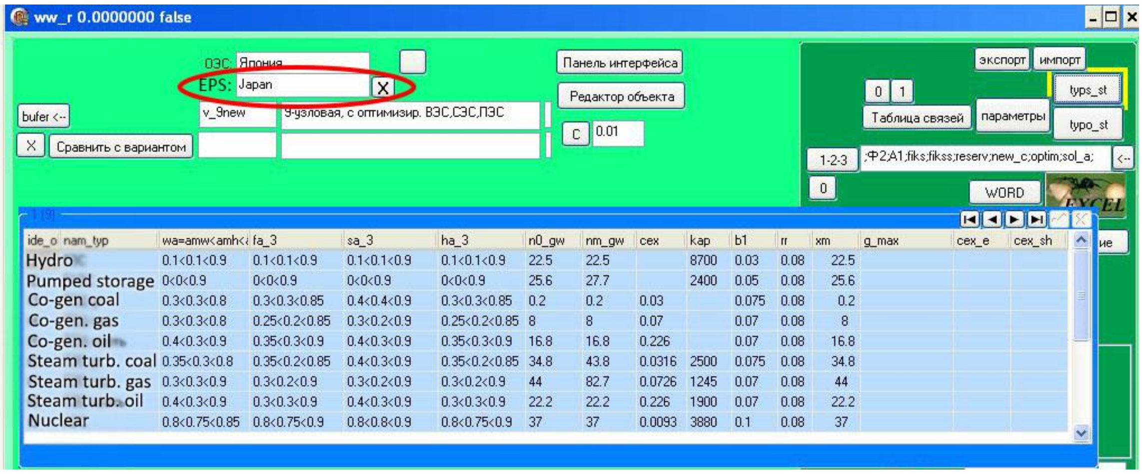

Fig. 1. Form of EPS parameters by generation type mix.

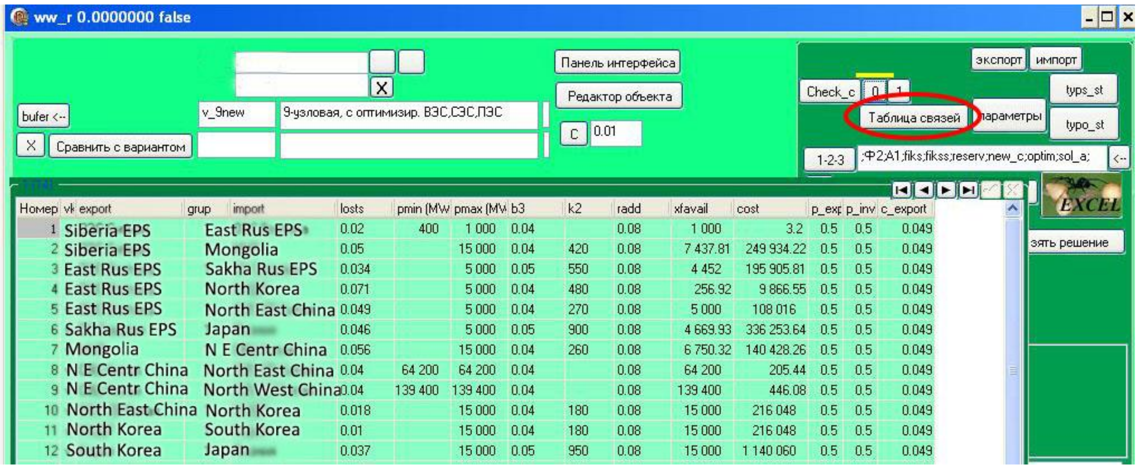

Fig. 2. Form of electric ties parameters.

B. One Form of Electric Ties Parameters for Each Scenario

There is only one form of electric ties parameters for each scenario. The form contains parameters of interconnections with transmission capacity between nodes of the grid scheme, Fig. 2.

These forms and tables allow CIS user to easy change the ISPG configuration (turning on/off the certain nodes on the grid scheme). After all settings of a specific scenario are completed, CIS user can starts the LP-optimizer process, which automatically generates and solves the linear programming problem (lp-problem) and finds the optimal solution for the given scenario. All scenario results are also stored in the OODB.

C. Scenarios Tree

The author's research is concerned with the construction and analysis of various scenarios of ISPG expansion. The authors have developed data processing algorithms for analyzing the results and comparing various scenarios. First, the main (base) scenario of the ISPG expansion in NEA is computed with the initial values of the model parameters set. All other scenarios are different variations of the main (parent) scenario. In the main scenario, it is considered and optimized the Isolated Operation and Expansion of each EPS without any interconnections. In the next scenarios, it is considered power systems interconnection with many options & variants.

The CIS interface implements the management of the scenarios tree. All variants have a meta-description. Any variant can be updated and reconfigured. It can also generate a series of variants that differ from each other by linear changes in one or more parameters.

V. Comprehensive Assessment of the Model Computation Results

The computation results for each scenario/variant at the output from LP-optimizer are characterized by a huge amount of data (several thousand rows).

As output parameters, the Model gets optimized installed capacities in each EPS and optimized capacities of electric ties. Meeting hourly electric load profiles in optimal way is also computed. The analysis of this huge amount of data is a non-trivial problem. For this purpose the authors have developed interactive interface forms. The computational results can be presented in tabular, graphical and cartographic forms.

A. Tabular Form

CIS allows one to create balance table, which shows how much electricity is generated by each type of power plants, how much electricity comes in and transmitted from the node, Table I. This data can be presented for different intervals: annual, year seasons, days and hours. Balance tables are generated automatically, after solving the LP-problem. The user simply needs to select the certain node and the time interval.

TABLE I. BALANCE TABLE FOR JAPAN EPS, 2035.

Electricity generation type	Annual electricity generation, GWh	Optimal installed capacity, GW	Annualized invest. costs, mln. $
Solar	15353	9.98	1598
Wind	15661	6.8	420
Pumped storage	12983	25.6	3072
Hydro	94568	22.5	21533
Steam turbine oil	48574	16.8	10978
Co-generation oil	58753	22.2	19605
Steam turbine gas	36331	8	2543
Co-generation gas	165529	44	15852
Steam turbine coal	226618	34.8	13686
Co-generation coal	1313	0.2	39
Nuclear	253746	37	28201
Subtotal	**929429**	**227.88**	**117527**
Sakhalin-Japan export	-24	5	1915
Sakhalin-Japan import	33129		
S. Korea-Japan export	-249	15	5614
S. Korea-Japan import	95921		
Pumped storage (accumulation)	-16229	-	-
Total	**1041977**	**247.88**	**125056**

B. Graphic Form with Combined Diagrams

A graphic form was developed to illustrate the scenario parameters for any EPS. In this form, the diagrams are combined with the initial (input) and optimized parameters, taking into account the optimal profile of the daily electrical load, Fig. 3.

Optimized capacities are showed between maximum and minim constrains on installed capacities expansion.

C. Cartographic Form

The scheme of ISPG can be represented on a world map. A grid scheme with optimized values is placed as a layer on a raster map. Raster and contour maps are built in the elliptical projection of Mercator, and can be represented as a hybrid map with satellite images, administrative divisions and names of geographical and energy/power objects.

All energy/power objects in OODB have their real geographical coordinates, which allows one to adapt (put) the grid scheme to any contour map. After setting all layers configuration, a hybrid satellite map with the scheme of ISPG is created automatically, Fig. 4.

This hybrid map shows the 10-nodes grid scheme of the prospective ISPG in Northeast Asia. Parameters of modeling nodes and their interconnections have been set in input forms (see Fig. 1 and Fig. 2) and optimized by the ORIRES model for 2035 target year.

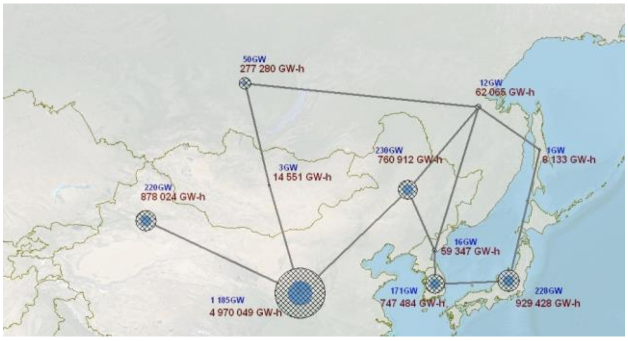

Fig. 4. Cartographic form.

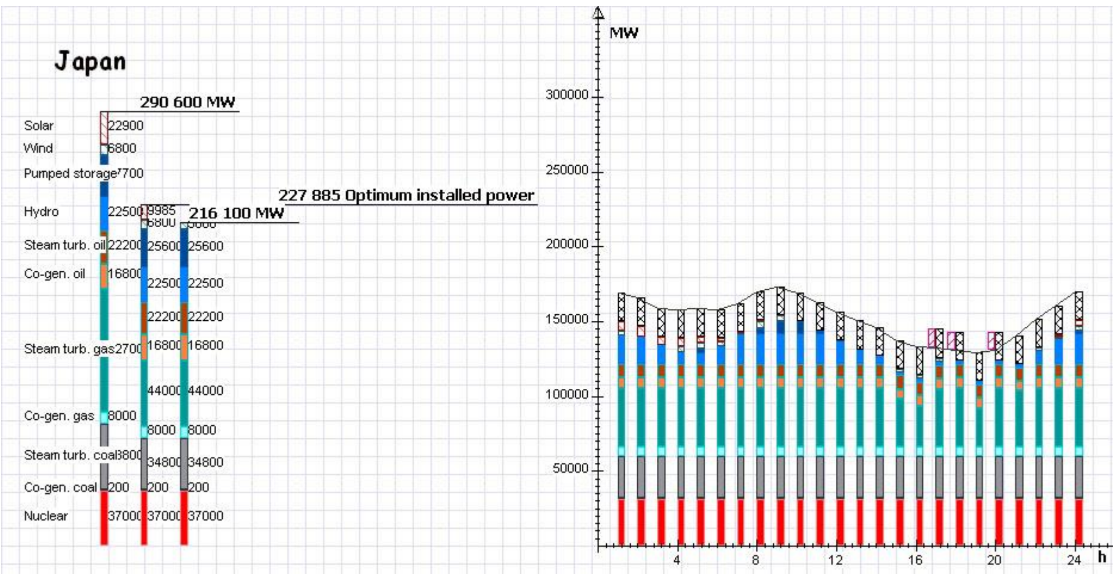

Fig. 3. Graphic form with combined diagrams.

A visual change on the map, combined diagrams and summary balance tables allows one to conduct a comprehensive assessment of the obtained results for various scenarios.

VI. Conclusion

The study of power system interconnection requires analyzing the huge amount of computational results. The research takes a great deal of time, without the problem-oriented software (CIS). Experts without the convenient user interface can hardly analyze the multi-aspect results. The data representation forms shown in this paper allow us to visually evaluate and analyze results from various scenarios of ISPG expansion. The automation of the creation output forms of the various scenarios with the ability to visually evaluate their differences allows one to improve the efficiency and quality of research.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Dr. Sergei Podkovalnikov leaded the conducted research, edited the paper. Mr. Leonid Trofimov developed the main program modules of the CIS and the energy database, made computations, analyzed the results. Mr. Ivan Trofimov prepared the input data, analyzed the results, and wrote the paper. All authors had approved the final version of the paper.

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