# Design and Implementation of an Intelligent Decision-making System for Power Grid Planning

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# Design and Implementation of an Intelligent Decision-making System for Power Grid Planning

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**Abstract**. In order to effectively cope with the situation of large amount of data, complex decision-making and lack of technical means in power grid planning, an intelligent assistant decision-making system for power grid planning based on platform design, visualization and advanced decision support function is designed and implemented. The system is closely integrated with Geographic Information System (GIS) and embedded in an integrated database. It has the functions of adaptability evaluation, investment priority decision-making, power grid reconfiguration scheme analysis and data interface of power grid simulation software. In the process of assistant decision-making, the coordinated evaluation of power supply and power grid is realized by the simulation of power grid dispatch, the investment priority of the project is determined by imitating the principle of static security analysis, the backbone network of power grid is identified by graph theory algorithm, and the data of the planning scheme is extracted from the newly developed simulation software data interface to reconstruct the topology and initialize the data of model.

## 1. Introduction

Power system planning is an important and complex preliminary work in power system construction. The planning quality directly affects the investment benefit and operation safety of power grid[1]. At present, Chinese power grid construction is moving towards a strong smart grid, which puts forward higher requirements for power grid planning[2]. So far, the researches of grid planning focus on discussing the mathematical model, and the traditional planning problem can be formulated as an optimization problem under certain constraints, such as optimization problems considering the vulnerability of power grid[3], power reserve capacity[4], security and stability constraints[5]. Because power grid planning needs to coordinate multiple relationships, it may present the characteristics of multi-objective optimization[3]. Therefore, its model belongs to the category of high-dimensional, non-linear mixed integer programming, and can can be solved by various optimization algorithms[6].

In the new era, power grid planning is facing the following main problems: 1) The coordination of power grid planning[7]. It is necessary to study how to grasp and coordinate power grid planning and power planning as a whole to ensure the coordinated and synchronous development of power grid construction and power construction. 2) The network reconfiguration scheme[8], which changes switch combination mode to make power grid operate in the most economical state. 3) Imperfect evaluation index system of power grid planning scheme[9-10]. Power grid planning must pay attention to the reliability and security of power grid, while more attention should be paid to the economy under power market environment, and the development of smart grid requires the evaluation of the environmental protection characteristics of planning scheme, etc. 4) There is a serious shortage of

information and intelligent support for power grid planning, and there is a lack of unified data platform support for power grid planning at present[11], and data collection takes a long time. The application of visualization technology such as Geographic Information System (GIS)[12-13] is limited. There is no automatic data interaction between power grid planning and power grid simulation. Besides urban distribution network planning, there is a lack of technical support for intelligent decision-making of power grid planning[14].

In view of the above aspects, this paper designs and implements a new intelligent assistant decision-making system for power grid planning, which introduces the latest research results in the fields of computer technology, GIS technology and power planning into power grid planning and provides decision support covering the whole planning process.

## 2. System Architecture

The system can be divided into four layers: The database layer, general component layer, business service layer and user presentation layer. The layers are separated from each other to facilitate the flexible expansion of the system. The overall structure the system is shown in Fig.1.
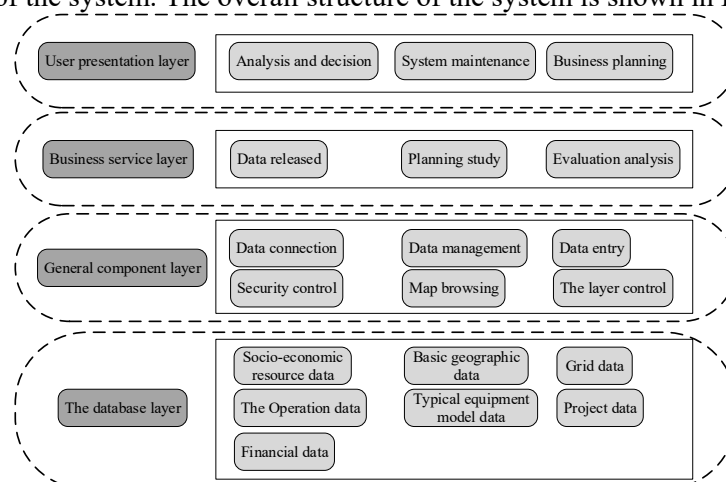


Fig. 1 Structure of the grid planning and managementdecision support system

1) Database layer. That is the planning database established at the bottom level, which is the basis of data management and sharing.

2) General component layer. As the basis of business service layer, it constructs general components by extracting similar functions on the basis of each functional module of the system, such as data connection, data management and so on. In order to avoid duplicate development, it can be extracted as a general component for the use of other application modules, so that when business changes, it can meet the requirements of all system modifications by modifying specific components.

3) Business service layer. It is the middle layer for planning, research, management, evaluation, decision-making and other work with various professional functions. It can be divided into two application modules: data publishing and planning research. It can provide services such as data publishing and displaying, power access assessment, load change assessment and planning evaluation.

4) User Presentation Layer. It is the highest level of the planning data management system module, and can provide users with a variety of application platforms. The users of this platform can be divided into three categories: leaders, system administrators and general users (planning staff).

## 3. Characteristics of the system

### 3.1Complete power grid planning platform

The system integrates the core functions of power system calculation and analysis software, GIS, medium and long-term load forecasting. It adopts the concept of business process-oriented integrated design and provides a platform-based planning and decision-making business solution, wihich realizes

a high degree of integration of data integration management and networked scientific computing and provides a powerful and flexible decision-making support platform for power system planning.

*3.2Comprehensive display platform of planning based on GIS*
The system provides a rich means of view display, and a visual cognitive and operational platform for planners. The system provides two visual interactive display modes of geographic wiring diagram and electrical wiring diagram for the same set of planning data, and realizes the function of automatically generating electrical wiring diagram from geographic wiring diagram. It can meet the needs of analysis and decision-making at different levels in the field of planning and the daily work of planning. In addition, the system also developed a comprehensive data display platform to show the results of planning and analysis. With this platform, the results of various planning and analysis can be viewed, as well as the results of various forms of analysis in hot spots.

In a word, the grid planning system based on GIS graphical operation interface provides a set of visual cognitive and operational platform, which displays the information related to the analysis and decision-making on the geographical map, so that the planners can intuitively understand the changes of grid information and realize the scientific and effective management of grid information, thus providing powerful technology support and decision-making support for grid planning.

*3.3Coordination evaluation of power grid planning scheme based on dispatching simulation*
In view of the limitations of the traditional evaluation methods of power grid planning schemes, such as incomplete evaluation, incomplete calculation of evaluation indicators, and difficulty in coordinated evaluation of power grid, the coordinated evaluation technology of power grid planning schemes based on dispatch simulation is introduced to adapt to various generation modes, which has the following advantages: 1) Considering both power grid planning schemes and power planning. 2) To simulate the generation situation in future years according to the actual dispatching work, and form the daily operation mode of evaluation year. 3) According to the simulated operation mode, calculate the reliability indicators such as section power flow, system reserve rate, load loss probability of power grid and other economic indicators, as well as the environmental protection indicators of power grid operation under different planning schemes.

The system uses coordinated evaluation technology based on dispatch simulation to calculate different planning schemes in depth and meticulously, and obtains multi-angle evaluation results, which reduces the dependence on experience and improves the scientificity of power grid planning.

*3.4Intelligent evaluation of power grid adaptability*
In order to improve the power grid structure in planning and design, it is necessary to analyze whether the current power grid can meet the requirements of power transmission and whether there is congestion in the power grid.

Intelligent evaluation of power grid adaptability is based on certain load demand and installed capacity of power supply, according to the principle of economy, to optimize the unit output, and then to evaluate the transmission capacity of transmission network to determine whether the development of transmission network is compatible with the growth of load demand, the growth rate of installed capacity of power supply, and whether there is an uneconomical situation of system operation caused by transmission network.

*3.5Investment priority decision technology for planning projects*
Different planning projects have different impacts on the reliability and economy of power grid. When the power grid construction funds are constrained, how to determine the sequence of project investment and construction is an important problem faced by comprehensive planning work of power grid enterprise. By introducing the technology of investment priority decision-making in power grid planning, the system establishes a scientific decision-making model, which fully considers the

investment cost and safety benefit of the project, thus realizing the project investment sequencing under the condition of limited funds.

*3.6Open data interface*
Opening data interface means that the system can realize data conversion with other power grid information systems through multiple formats of interfaces. At present, the system mainly includes SHAPE, CAD, SVG, BPA and other format interfaces. The system automatically extracts the basic data needed for planning in power grid information system (such as GIS, SCADA, PMIS, etc.), and automatically generates land blocks (geographic wiring map background) using SHAPE or CAD format files. It can also realize the graphical output of planning results (AutoCAD, jpg, etc.), the generation of thematic analysis charts, and the generation of GIS thematic maps (realizing the use of GIS maps and other satellite maps to show the planning results). In view of the wide and successful application of BPA program, the system also achieves connection between BPA programs. Flexible and open data interface effectively integrates various resources of different information systems in power grid, and improves the sharing of planning data and expands the application scope of planning results.

## 4.  Model and evaluation system
The system uses a large number of theoretical research results to provide technical support for the application, evaluation and decision-making functions. The models used mainly include Load forecasting model, power grid coordination evaluation model, power grid adaptability intelligent evaluation model, network reconfiguration model and investment priority decision model.

*4.1Load forecasting model*
The system provides a forecasting model base of more than 50 models, including exponential model, dynamic average model, grey forecasting model and comprehensive forecasting model. It can forecast annual or monthly maximum load, electricity consumption and typical daily load curve. It also provides credibility index to help users choose models and form comprehensive forecasting results with high forecasting accuracy.

*4.2Coordination evaluation model of power supply and grid*
The model consists of generator maintenance optimization arrangement, multi-day operation coordination and daily operation optimization simulation. Among them, the daily operation simulation model is the core, which consists of four parts: 1) Simulation calculation of non-optimal operation units. 2) Peak shaving optimization of hydropower and pumped storage units. 3) Unit combination. 4) Integrated simulation calculation of power supply and power grid.

The model considers complex constraints such as system balance, grid constraints, start-up and shutdown of unit, peak shaving and so on. It can be briefly described as follows:

$$\min F = \sum_{t=1}^{T}\sum_{i=1}^{n}[u_{it}f_{it}(p_{it})+u_{it}(1-u_{i(t-1)})S_{i}]$$

$s.t.$

$$\begin{cases} \sum_{i=1}^{n}u_{it}p_{it}=\sum_{j=1}^{m}L_{jt} \\[2mm] \sum_{i=1}^{n}u_{it}(p_{i\max}-p_{it})\geq R_{t} \\[2mm] p_{linek}=\sum_{l=0}^{N}x_{kl}p_{inj,busl}\leq p_{k\max} \\[2mm] p_{it}\leq p_{i\max} \\[2mm] -r_{di}\Delta t\leq p_{it}-p_{i(t-1)}\leq r_{ri}\Delta t \\[2mm] u_{it}\in\{0,1\} \end{cases} \qquad (1)$$

Where $f_{it}$ is the generation cost of unit $i$ in time period $t$; $S_i$ is the start-up cost of unit $i$; $u_{it}$ is the operation state parameter of unit $i$ in time period $t$; $p_{it}$ is the output of unit $i$ in time period $t$; $L_{jt}$ is the load of unit $j$ in time period $t$; $p_{imax}$ is the maximum output of unit $i$; $R_t$ is the system standby requirement of time period $t$; $p_{linek}$ is the current power flow through line $k$; $x_{kl}$ is the linear transmission factor of the bus $l$ of the transmission line $k$; $p_{inj, bus}$ is the injection power on the bus $l$; $p_{kmax}$ is the maximum transmission capacity of transmission line $t$; $r_{di}$ is the maximum reduction output rate of unit $i$; $r_{ri}$ is the maximum increase output rate of unit $i$; $\Delta t$ is the time interval; $m$, $n$, $T$ and $N$ are the load number, the number of units, the number of nodes and the number of time interval, respectively.

*4.3 Intelligent evaluation model of power grid adaptability*

The principle of the intelligent evaluation model of power grid adaptability is to calculate the output of generation of units and the power flow respectively on the basis of the current power grid, considering or not considering the transmission limit of the line. Comparing the change ratio of line power flow in two cases, and the investment benefit of line with large change ratio is higher.

The adaptability evaluation model includes thermal power unit generation optimization and power flow evaluation model. The unit-by-unit input mode is adopted to optimize the output of thermal power units, giving priority to determining the output status of units with the most economical operation cost until the load is fully satisfied or there is no unit to be started. The unit output under two modes with or without network constraints is calculated respectively. The vector $\theta$ can be calculated by formula (2) and the branch power flow can be calculated by formula (3):

$$P = B\theta \qquad (2)$$

$$P_{ij}=-B_{ij}\theta_{ij}=\frac{\theta_{i}-\theta_{j}}{x_{ij}} \qquad (3)$$

Where $P$ injects power vector for nodes; $B$ is imaginary part of node admittance matrix; $\theta$ is phase angle vector of node voltage; $P_{ij}$ is power flow of line $(i, j)$; $\theta_i$ and $\theta_j$ is voltage phase angle of nodes $i$ and $j$; $x_{ij}$ is impedance of line $(i, j)$, respectively.

For transmission lines $(i, j)$, the line power flow is recorded as $P_{ij}$ and $P_{ij}'$ when considering and not considering network constraints. Compare the change ratio $r$ of the two kinds of power flow, and the transmission line with larger change ratio has higher investment benefit. $r$ is calculated according to formula (4):

$$r = \frac{P_{ij}' - P_{ij}}{P_{ij}'} \tag{4}$$

*4.4 Network reconfiguration model*

When the system is in normal state, it is desirable to minimize the network loss in order to improve the economy. When the system is in failure state, it is desirable to restore the power supply to the maximum extent. Therefore, the objective function is expressed as follows:

$$\min f = e \sum\nolimits_{l=1}^{m} k_l r_l I_l^2 + (1-e) \sum_{i \in A} P_i \tag{5}$$

Where $m$ denotes the total number of branches in the network; $e$ denotes the system state: 1 for the normal state, and 0 for the failure state; $k_l$ denotes the state of switches on branch $l$: 1 for closure, and 0 for disconnection; $r_l$ denotes the resistance on branch $l$; $I_l$ denotes the current flowing through branch $l$; $A$ denotes the set of nodes that have not restored power supply; and $P_i$ denotes the load of node $i$.

Constraints such as power flow balance, node voltage constraints, branch current constraints, transmission power constraints and network topology constraints are met in the process of distribution network reconfiguration, as described below:

$$\begin{cases} F(P_i, Q_i, V_i) = 0 \\ V_{i\min} \leq V_i \leq V_{i\max} \\ I_l \leq I_{l\max} \\ S_l \leq S_{l\max} \\ R \in G \end{cases} \tag{6}$$

Where $P_i$, $Q_i$ and $V_i$ represent the active power, reactive power and voltage of node $i$; $V_{imin}$ and $V_{max}$ represent the minimum and maximum voltage allowed by node $i$; $I_{lmax}$ represents the maximum current allowed by branch $l$; $S_l$ represents the transmission power of line $l$; $S_{lmax}$ represents the power transmission limit of line $l$; $R$ represents the network structure of scheme and $G$ represents all feasible structure sets, namely radial network.

*4.5 Omni-directional and multi-dimensional evaluation system of power grid planning scheme*

In the process of system construction, many indicators reflecting the essential characteristics of the planning scheme will be scientifically classified and combined. A power planning evaluation index system including environmental protection analysis, reliability analysis, standby analysis, power flow and utilization analysis, power analysis, power supply analysis, load analysis, investment benefit analysis and other data topics will be designed and established[9]. For example, environmental protection indicators are included in the evaluation index system of power grid planning, which reflects the development requirements of low-carbon power.

The system further realizes deep reprocessing of index connotation through advanced simulation technology, and comprehensively improves the information content and value of index system. At the same time, it will be integrated into the calculation results analysis and decision-making function module to achieve a comprehensive, multi-dimensional analysis and evaluation of the planning plan from different time dimension and analysis dimension. The evaluation index system of power grid planning is shown in Fig. 2.
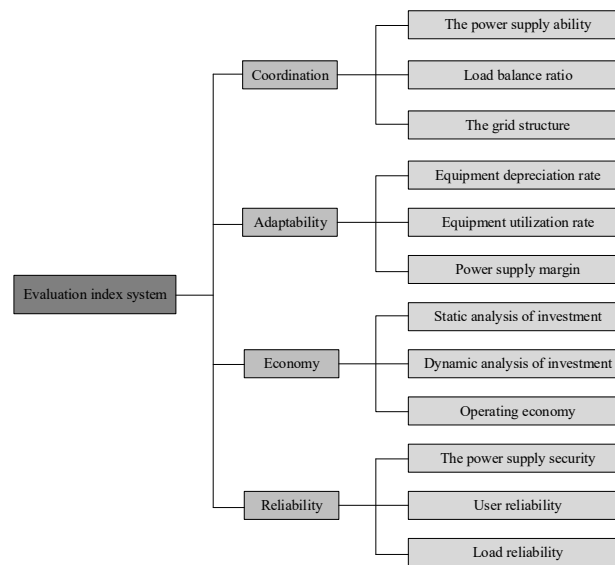
Fig.2 Evaluation system of grid planning

## 5. System function analysis

According to the needs of business process, the intelligent decision support system for power grid planning can be divided into eight functional modules from the perspective of system function design, as shown in Fig. 3.
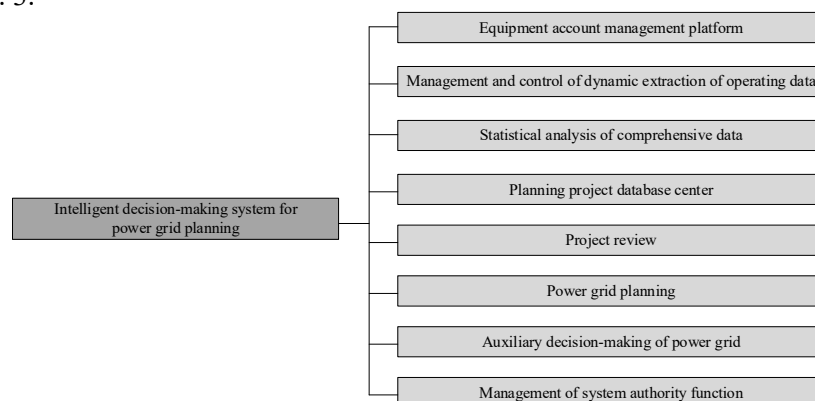


Fig.3 Main functional modules of intelligent auxiliary decision making system for power grid planning

The planning decision system covers the whole process of the main network planning. It can complete the power planning and power grid planning in the system. At the same time, it has the function of evaluating the adaptability of the grid and the feasibility of the planning scheme. It is an intelligent assistant decision-making system for power network planners and managers. Its main functions are as follows.

### 5.1 Equipment account management platform

Functional modules include "Substation Information Management", "Transformer Information Management", "High Voltage Line Information Management", "Medium Voltage Line Information Management", "Medium Voltage Contact Information Management", "Low Voltage Equipment Information Management", "Interval Information Management" and so on. Each function includes general addition, deletion and modification, which can be queried jointly and quickly. It can also customize condition query, custom export and intelligently correct error.

There is a topological relationship between the devices, and there will be no duplicate values. The devices have access rights so ompanies in different cities can only see their own devices.

*5.2Management and control of dynamic extraction of operating data*
Functional modules include "Substation Information Management", "Transformer Information Management", "High Voltage Line Information Management", "Medium Voltage Line Information Management", "Medium Voltage Contact Information Management", "Low Voltage Equipment Information Management", "Interval Information Management" and so on.

The system accesses the SCADA three-zone WEB server, and uses computer processing to screen out the desired data for processing and display. For example, the substation will collect the maximum monthly load on the three sides of the transformer, and at the same time collect the current and reactive power of the transformer at this load moment, and calculate the apparent power, power factor and load rate. The report forms and statistical analysis are directly formed after collection, which greatly saves working time.

*5.3Statistical analysis of comprehensive data*
The modules of multi-dimensional information analysis in the system include "Substation Information and Analysis", "High Voltage Line Information and Analysis", "Medium Voltage Line Information and Analysis", "Substation Operation Information and Analysis", "High Voltage Line Operation Information and Analysis", "Medium Voltage Equipment Operation and Analysis" and so on.

By using OLAP (Online Analytical Processing) component of Oracle 11G database and DevExpress page component, the multi-dimensional analysis of power network planning information is realized, which greatly improves the efficiency of power network planning information analysis.

For example, in the "Substation Information and Analysis" module, the number of substation seats, main transformer stations, transformer capacity, reactive power compensation capacity, the total number of outlet intervals of each voltage level, the number of used intervals and other information can be statistically analyzed from various dimensions such as voltage level, region, mode of use (public or special), urban and rural power grid.

*5.4Planning project database center*
Establish the management interface of power grid project plan (including planning database). In order to form different project plans, the project types include high voltage, medium voltage, marketing, automation and so on, according to the features of work.

Modify the details of the project according to the State Grid planning template and cancel the project package interface. A project cost database is established, which can estimate the investment by itself according to the scale of the project. It has multi-dimensional analysis of equipment scale and investment of distribution transformer, circuit, switch and reactive power compensation in the project. The project implementation plan can be fed back to the grid status information according to the project operation situation, including the number of main transformers, capacity, number of intervals used, number of lines, length and so on.

*5.5Planning project review*
After establishing the power grid project scheme, the scheme can go through the system review process. At the same time, the graphical platform can be invoked to display the load and the approximate location near the scheme, which is convenient for leaders to quickly review or discuss. After approval, the project can be automatically added to the equipment library after completion of the process.

*5.6Power grid planning*
The module can obtain the forecasting results of electric power quantity and the installed capacity results of power planning directly, and calculate the demand of transformer capacity and make decision of substation location according to voltage level, and then plan the transformation network according to the distribution of power plants, substations and transmission lines on GIS, so as to realize the separate management of different planning schemes.

*5.7 Auxiliary decision-making of power grid*

By using the results of the index system of system environmental protection, safety, economy and reliability evaluation, we can make a comparison of the designated indicators between project plans and different planning plans, and make a decision of power grid planning plans according to the merits and demerits of the indicators. After choosing the planning scheme, if the construction fund is limited, the N-1 check simulation can be made by using the priority decision function of the project to get the system-wide evaluation index when there is no project. And then the items in the planning scheme are ranked according to the importance, and then the items in the front rank are selected according to the allowable amount of funds.

*5.8 Management of system authority function*

It includes role management, authority management, user management, unit management and interface management.

Data backup and recovery: In order to ensure that the regional power grid planning support system can run correctly and steadily, and prevent the loss of data caused by some man-made intentional or unintentional operation or even cause the collapse of the whole system, the system can be quickly and effectively restored, and the system provides data backup and data recovery functions.

System authority management: The system adopts modular framework system, which can realize the self-reconfiguration of system functions according to requirements. The function configuration is flexible, and the functions and authority can be set flexibly according to different organizations for different positions.

## 6. Conclusion

The complexity of power grid planning determines the difficulty of the construction of planning decision support system. The intelligent decision support system for power grid planning introduced in this paper has built an integrated database covering the whole planning process. It has the characteristics of visualization of planning results and intellectualization of decision-making. It can provide auxiliary decision support for power network planning. Its characteristics are as follows:

1) Improve the effectiveness of planning decision-making. The system combines power grid planning with urban planning on the data platform, and make rational use of urban resources to make more effective management of planned reserved stations and pipelines, so it avoids waste of urban resources and power grid resources, which harmonizes power grid planning with urban planning and makes the planning more feasible and economical.

2) A grid planning platform based on GIS is established. With the help of GIS platform, the system can display multi-year and multi-plan power grid planning information at the same time, and can meet the needs of different levels of planning, detailed analysis of different data and daily planning work.

3) Improve the daily management level of planning. This system realizes the functions of fast and practical "automatic N-1 check" and "3T wiring check", and provides practical functions such as comparison of planning schemes and automatic generation of planning reports, which greatly improves the work efficiency of planners and meets the daily needs of planners.

4) A unified power grid planning platform is built. With the help of flexible and open data interface, the system is well embedded in the information system of power grid company. It effectively integrates the whole information system resources, solves the difficult problems of planning informatization and routinization in basic data acquisition, and provides a unified working platform for power grid planners.

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