

Analysis on Visualization Technologies of Flow Calculation

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Abstract—Visualization technologies of complex power grid become more and more important because of the enlargement of grid scale. Combining the analysis processing of complex power grid with visualization technologies based on geographical information, visualization analysis model of flow calculation has been developed on the integrated development platform of PowerBuilder and MapInfo in this paper. Functions, system architecture and data structures of the analysis model were firstly designed, and the key technologies and their implementation were also discussed. According to the presented analysis model, the influence of power grid failure to urban power can be analyzed, and power supply states under different operation modes can also be dynamically and intuitively represented. The feasibility and practicality of the model was verified by giving an example of an IEEE 14-node grid.

Keywords- visualization flow calculation; PowerBuilder; MapInfo; OLE

1. Introduction

With the development of complex grid network, visualization technologies become more and more important for it. The power software, base on a graphical user interface, can not only display [1-2] various properties of electrical equipments, but can also display system status and a variety of indicators, all in the form of digits or graphics, making it easy for the operators to understand the current system status. PowerWorld [3], a professional analysis software abroad, can vividly perform the model construction, analysis of system steadily, dynamically and economically operation, and can simulate power trading. Most of the software is based on the cross-section data. However, as the deepening dependence on the power to society, a lot of non-electrical areas need more and more power grid analysis, including the analysis of the changing progress and influence by disaster to the grid. Therefore, it demands the analysis software to be visual in order to meet the need of more functions and non-professionals.

In this paper, an application system with powerful capabilities of map processing and grid analysis will be developed on the platform of PowerBuilder, MapInfo and BPA (Bonneville Power Administration). The application system can show power system status and changes in the form of graphics. Besides, combining geographical spatial data with electrical data, the power distribution in the region under an emergency can also be analyzed. The overall design and key technologies will be firstly presented, and then an example of IEEE 14-node grid will be illustrated.

2. Analysis System Design

The power grid analysis model in the visualization system contains 6 functions as below.

2.1. Design Analysis

1) Graph-model Integration

Based on geographic information system (GIS), the grid topology structure needs to be built in the form of graphics, and the equipments, properties and status data should be maintained. Once the topology structure is

changed, the systematic relationship data and state data should be automatically updated, realizing the graph-model integration [4-6].

2) *Steady State Analysis of Complex Grid*

For the high voltage distribution grid, the load at load buses and operating data of generators should be imported according to operating mode and time section.

Steady state calculations, including flow calculation, short-circuit current calculation, should then be accomplished by invoking BPA.

The calculation results are required to be shown on the graphical interface quickly, direction of flow being shown on the high voltage lines, the load rate of lines and substations being shown by the related nodes, and the status of the load—reasonable or overload—being illustrated by different colors. [7]

3) *Regional Power Situation Analysis*

- Spatial load distribution: Firstly, establish a load property graph according to the block division by the city planning department. Load data forecasted in the passed several years should then be overlay on the block graph. The load distribution over different blocks, and load data of large consumers can be finally queried.
- Power supply range: According to the topology, the power supply range centered by each substation has to be colored, whose proportion, power supply ability and load condition should also be marked.

4) *Fault Influence Analysis*

In this analysis module, the substations, transformers or lines may be considered as the fault objects. Choose one or more fault objects to analyze the corresponding topology and to calculate with BPA. From the calculation results, we can figure out in which region it is power outage, or shortage, or normal, each being displayed with different colors.

5) *Graphic Management*

This functional module manages all the graphic layers of land blocks. Users are free to add new layers for other terrains and contours, and so on. Some common operations, such as zoom and roam, should also be achieved.

6) *Data Maintenance and Output*

The basic maintenances to the general data sheet (i.e. user information, basic grid parameters, and load) should be presented. The calculation results can be queried, counted and output in the form of EXCEL reports.

2.2. The Software Architecture

Basing on Windows XP, this system is developed by integrating the software of SQL Server, MapInfo Professional 9.5, BPA, and PowerBuilder. The software architecture is based on C/S mode as is shown in Figure 1.

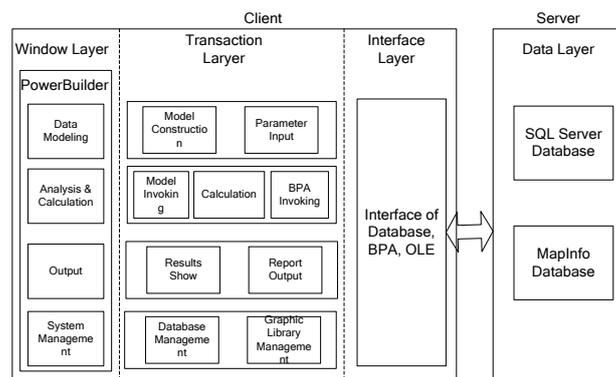


Figure 1. System architecture

The client includes the window layer, transaction layer and interface layer, while the server is the data layer. In the window layer, PowerBuilder invokes the OLE automatic server of MapInfo through the transaction layer and interface layer. The map window in MapInfo, which is controlled by MapBasic, would be integrated into the client system. The transaction layer is the function model of transaction processing. The

interface layer provides interfaces between transaction and the server, including database interface, BPA interface and OLE interface. The data layer is the database server of SQL Server and MapInfo.

2.3. Data Structure Design

In this system, data is modeled basing on IEC 61970 and CIM which describes the relationships and properties of electrical devices. Core package and line package of CIM are used to construct all the electrical data structures. Besides, the operations in CIM, such as inheritance, association, aggregation and composition, are realized by the mapping of primary key to foreign key.

There are 3 categories of information related to the geographic: geographical background, electrical information and emergency information. Each category includes some graphical layers illustrated in Table I. The emergency layer contains urban land information, and power of each land block is supplied by a corresponding grid; the electrical layer relates to electrical information; the geographic background can be in the form of vector or raster, but in practice, the raster images should be adjusted according to accurate control points.

TABLE I. INFORMATION TYPES OF THE SYSTEM

| Information Type | Specific Information | Layer Type |
|------------------------|-----------------------|-----------------------|
| Electrical Information | Calculation Result | Electrical Layer |
| | Topology | |
| | Electrical Device | |
| Others | Land Mass | Emergency Layer |
| | Emergency Information | |
| | | Geographic Background |

Each electrical component on the graphic platform is represented by graphic properties, electrical characteristics and relationship characteristics. Electrical characteristics are defined according to the related models in Domain package. And electrical parameters are related to the graphic properties by the unique handle of each device, realizing the integrated model of graphics and database.

3. Key Technology

3.1. Graphical Display of the Analysis Result

It is a basic function of steady-state analysis, regional power situation analysis, and failure influence analysis. The main task is to display any analysis results on the geographic window. In order to integrate PowerBuilder and MapInfo, the interaction of front display and background processing should be firstly resolved. The interaction progress includes 3 steps: OLE objects construction, connection to the server, and interactive call-back.

1) OLE Objects Construction

In order to integrate the geographic window of MapInfo into client system, a new parent window should be assigned in PowerBuilder for the application window of MapInfo. A "Picture" control should then be added to the parent window. Meanwhile, one new OLE object whose OLE server is assigned to be MapInfo should be created in the window event, resulting in the integrated display in the window.

2) OLE Objects Connection to the Server

OLE automatic technology will be used to attain the connection and disconnection of the client program to the server.

A "ConnectToNewObject()" function should be firstly invoked to create the connection of the objects to the OLE server. After the object-ID being transmitted, and the MapInfo services being invoked, the connection is then completed.

When quitting, the "DisconnectToObject()" function would be invoked to disconnect the connection, and OLE objects would also be removed in order to release system resources.

3) Interactive Callback

To control the integrated graphic window in PowerBuilder client program, OLE automatic objects are needed. The response events to the operations on the graphic window are only delivered to MapInfo server, rather than the client program. Consequently, in order to solve the events in the client, callback technology should be adopted, the principle of which is illustrated in Figure 2. An operation event has to be defined in the client program of PowerBuilder. When there is a window operation event, the MapBasic program in MapInfo server will be invoked. At the same time, a message will be transmitted to the user-defined-events of PowerBuilder client, controlling the integrated graphic window.

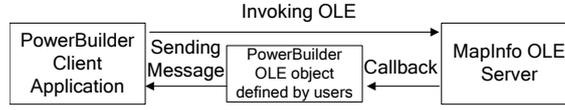


Figure 2. Principle of callback between PowerBuilder and MapInfo.

3.2. Dynamic Display

Dynamic trajectory based on GIS is widely used in GPS positioning and hot spots tracking. This technology will be used in this paper for the dynamic display of flow [8]. There are 2 methods to achieve this technology, one is to update the position by offsetting the original coordinates, and the other one is to add a new point in the new position after deleting the original one. The former is adopted in this paper.

Some arrows are uniformly-spaced inserted along the line whose length determines the number of arrows. The coordinates of the arrow objects are stored, and they are divided into two groups to alternately display, realizing position offset. The length of line can be calculated according to Formula (1); and the angle of each arrow should be adjusted by $90^\circ \pm \theta$ or $270^\circ \pm \theta$ according to the coordinate characteristic of the first node and final node. The angle θ is calculated by Formula (2).

$$Len = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (1)$$

$$Angle = \arcsin\left(\frac{|x_2 - x_1|}{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}}\right) \quad (2)$$

Considering that the grid is complex and there are many geographic objects, the dynamic changing speed of these objects should be optimized. Consequently, all the lines had better to be integrated into a multi-point object which is constructed on top of the dynamic layer. As a result, the integrated geographic window will be more easily to control, and the fluency of dynamic display will also be improved.

3.3. Analysis Result Display

When there is a failure, the actual effects to the load in each region can be figured out by BPA which applies a regional coloring technique.

In this technology, one region corresponds to an impact factor which refers to a different color. The method to calculate the impact factor is as seen in Formula (3), where “*enum*” stands for the number of land block, “*stnum*” stands for the grid node number, “ $P_{i,j}$ ” stands for the relating factor between the node and the land block, “ $L_{i,j}$ ” stands for the load of land block i provided by node j , “ $\mu_{i,j}$ ” stands for the influence factor from node j to land i .

$$\mu_{i,j} = 100\% \times \frac{L_{i,j}}{L_{i,j} \times \sum_{i=1}^{enum} \sum_{j=1}^{stnum} P_{i,j}} \quad (3)$$

Consume the regional color corresponding to $\mu = 100\%$ is pure black —RGB (0, 0, 0). The offset of color changing can be achieved by Formula (4).

$$Offset_i = \mu_{i,j} * 255 \quad (4)$$

And then a new regional color can be achieved by RGB ($Offset_i$, $Offset_i$, $Offset_i$). But for simple, $RGBVal$ is calculated as Formula (5).

$$RGBVal = 256^2 * red + 256^1 * green + 256^0 * blue \quad (5)$$

In this paper, the method to fill the effected areas with different color is gradually fading from dark to light. In order to emphasize different degrees of influence, color ranks can be set according to the impact factors.

3.4. BPA Interface to Transient Analysis

BPA is one of the important tools for power system analysis and calculation, which can calculate rapidly the transient stability of large-scale complicated grid. But only one time can be used for one operation state with BPA, otherwise the parameters of operation state should be manually modified. In order to improve the calculation speed and efficiency, an interface to BPA, which invokes the file reading and writing commands to solve the stability calculation results in every fixed period, is designed as is shown in Figure 3.

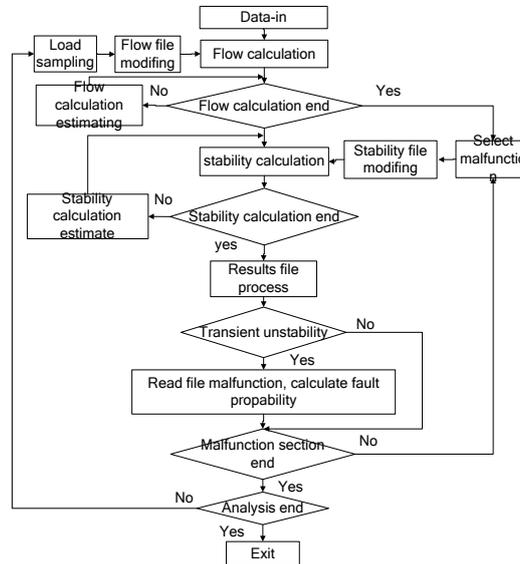


Figure 3. Flow chart of BPA Interface.

In this procedure, the automatic modification of load flow is realized by sampling a simulate normal distribution load in PowerBuilder; a tube technology is used to detect the flow calculating progress; the stability calculation progress of BPA will be compulsively closed after a fixed period; after stability calculating, the grid transient stability can be estimated according to the power-angle in different fault time points [9]. For the situation of transient instability, the related parameters (such as fault probability) should be stored in the database.

4. The Designed System

4.1. An Example of the Stability Analysis and Display

Taking an IEEE grid with 14 nodes as an example, the visual analysis of flow calculation will be accomplished. The structure of the grid is shown in Figure 4.

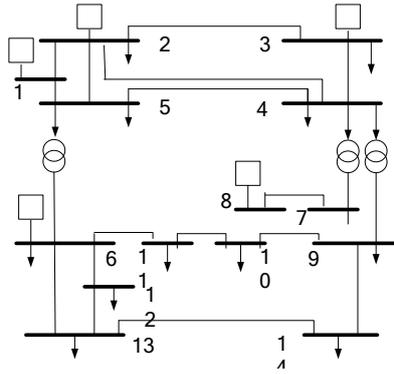


Figure 4. IEEE 14-node grid.

A grid model should be firstly constructed in the system based on the grid structure and related data. Taking the grid structure as the geographic background, the 14 nodes and lines are distributed, constructing an equivalent topology as shown in Figure 5. The tree menu on the left of the system platform is the function module zone, while on the right it is the zone to display the grid model. Because an equivalent topology and different device layers are used, the grid structure in an actual application is more clear and intuitive.

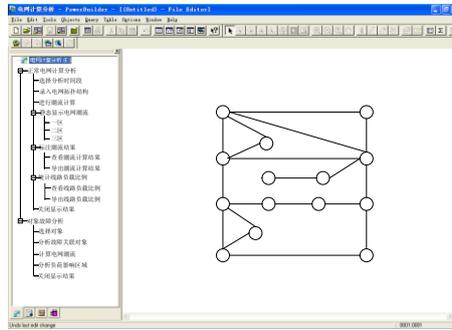


Figure 5. The equivalent topology in the analysis system.

After importing the grid topology and parameters, flow under stable state and short-circuit current can be calculated. The dynamic display of grid flow is as seen in Figure 6. The calculated flow values and directions are marked. While in Figure 7, load condition of each line is displayed in the form of pie charts where the load and residual capacity of the current line are respectively marked with blue and white, making it clear for the users.

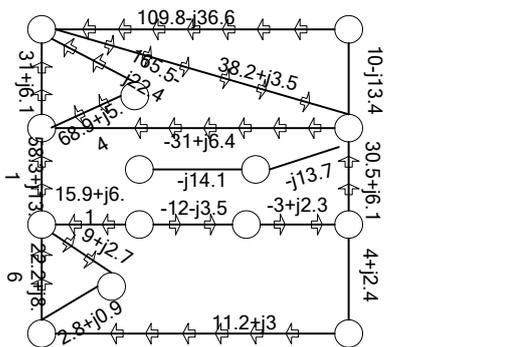


Figure 6. Dynamic display of flow value and direction of each line.

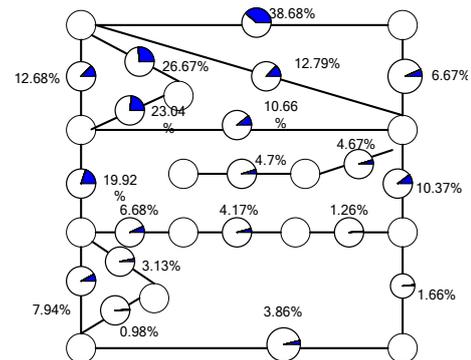


Figure 7. Load condition of each line.

4.2. Regional Analysis under a Failure Situation

The presented system allows users to simulate power grid failure. Consume there are five electric generator sets in the 14-node grid, respectively located in node 1, node 2, node 3, node 6 and node 8. The influence of node 4 failing will be analysed as below:

- Choose node 4 as a fault point in the “Selecting Objects” module, and then the system automatically locates the node and marks it with a red cross.

- The application of the “related objects to the failure” module may highlight the related branches with red colour. As is seen in Figure 8, the related branches to node 4 are the branches from node 4 to node 2, node 3, node 5, node 7 and node 9.
- Invoke BPA to calculate the flow, and then set the related areas with different colours according to their own load value.

Consume that each total load value in area 3, 4, 5 and 9 is 100MW. Areas 3, 5 and 9 are powered by more than one node, while area 4 is powered by node 4. The degrees of load loss in area 3, 4, 5, 9 are respectively 10%, 100%, 31%, 30.5%, according to which the color levels are determined—in this paper, 6 levels are determined—resulting in Figure 9.

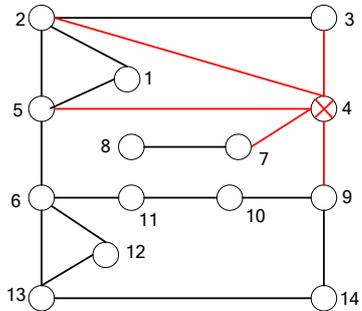


Figure 8. Related branches to the failure node.

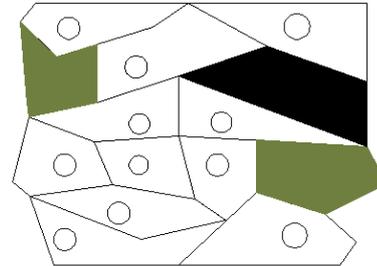


Figure 9. Related load to the failure node.

Table II shows both the load ratio and load loss of each line under a normal or failure state. Only those lines whose load ratio under normal state is more than 10% are list in the table, the number of which is 8. Line 9 and line 10 are both the equivalent line of transformer, so their resistances and line losses are all 0. When in failure, line 4, 6, 7, 8, and 9 are all disconnect, and all of their loads are 0. While the load of line 5 increases from 10.5% to 16.3% under normal state, and line 10 from 19.9% to 34.2%. The changing magnitudes of the other lines are within 8%. This shows that the failure little impacts on the regional power supply. That’s because when node 4 fails, the line between node 4 and node 7 breaks, and the grid separates into 2 sub-grids where node 8 is powered by node 7, consequently the grid is still in normal state.

TABLE II. LINE ANALYSIS UNDER NORMAL AND FAILURE STATE

| No. | Line Load Ratio | | Line Loss | |
|-----|-----------------|----------------|---------------|----------------|
| | <i>Normal</i> | <i>Failure</i> | <i>Normal</i> | <i>Failure</i> |
| 1 | 55.7 | 41.6 | 4.79 | 2.67 |
| 2 | 23 | 22.6 | 2.32 | 2.28 |
| 3 | 38.6 | 33.8 | 5.7 | 4.38 |
| 4 | 12.8 | 0 | 0.79 | 0 |
| 5 | 10.5 | 16.3 | 0.53 | 1.27 |
| 7 | 10.7 | 0 | 0.13 | 0 |
| 9 | 10.4 | 0 | 0 | 0 |
| 10 | 19.9 | 34.2 | 0 | 0 |

In addition, not only the single point failure, but also the source failure and multi-node failure can be simulated in this presented system.

5. Conclusion

In the integrated platform of PowerBuilder, MapInfo and BPA, the visual system of power grid analysis is developed. The data processing capability is improved while the visualization is ensured. This system can not only be used to simplify the grid structure, but also to visually calculate and analyze, simulate the failure state and the areas affected by failure. Besides, it can assess the vulnerability and security of the entire grid. It’s a very useful system for decision support.

6. References

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