Research on Risk Assessment of Power Grid Based on Real-time Simulation System

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Abstract. In order to ensure the safe and stable operation of the power system, the importance of power grid calculation in simulation analysis has become more and more prominent. It is particularly important to carry out power system hidden danger investigation and risk assessment for large power grids. This paper builds a "power system full-digital real-time simulation platform" based on ADPSS. Through the modeling of the actual power grid and full fault scanning, the existence and probability of risk, the scope and degree of loss are evaluated and measured, and the operation of the power grid is analyzed. The safety and stability of the power grid, while identifying weak links in the power grid. This assessment method can provide technical support for the investigation and management of hidden dangers in the power grid, and has certain practical significance and positive guidance for the stable operation of the power grid.

1. Introduction
Power grid calculation plays a very important role in power grid operation control. Because it is extremely difficult to test on the actual system, the only way to study the power grid operating characteristics and verify various control and protection measures is through simulation test simulation, which is particularly important for the stable operation of the power grid. Through modeling and simulation of the actual power grid to find out the weak links of the power grid, assess the risk level of the power grid, do a good job in the investigation and management of hidden dangers of the power grid, and pre-analyze the power grid projects that are planned to be put into operation. It is useful to locate the weak links of the power grid and guide the actual operation of the power grid. [1-2].

Heilongjiang Province is the most northeastern province of our country. The north and east are bounded by Heilongjiang and Ussuri Rivers, facing Russia; the west is adjacent to the Inner Mongolia Autonomous Region; the south is bordered by Jilin Province. With the rapid growth of power demand and the continuous expansion of the scale of the power grid, the safety of the power system operation in Heilongjiang Province has increasingly become the focus of attention. Therefore, it is of great practical significance to carry out risk assessment of the power grid, find the weak links and give treatment to improve the overall reliability of the power grid and reduce the risk of power grid operation [3-4].

This paper establishes a power grid risk assessment model of a fully digital real-time simulation system, models the actual power grid and scans full faults, evaluates and weighs the existence and probability of risks, the scope and extent of losses, and evaluates the safety and stability of power grid operation. And finally establish a data reserve database of hidden dangers in the power grid. The evaluation method in this paper provides technical support for the investigation and management of hidden dangers in the power grid, and has certain practical significance and positive guidance for the stable operation of the power grid.
2. Calculation tools and research methods

2.1. Component model
In the reliability analysis of the power generation and transmission system, the Markov model is the basic component model. For the three types of components of line, transformer, and bus, all of them can be described by the Markov model. The reliability model of the component generally adopts the traditional two-state model [5-6], as shown in Figure 1.

![Figure 1. Two state model](image)

In Figure 1, N is the normal state, R is the fault repair state; λ is the failure rate, μ is the repair rate, and the relationship between λ and μ, MTTF and MTTR is:

\[ \lambda = \frac{1}{MTTF} \]
\[ \mu = \frac{1}{MTTR} \]

For any component \( k \) in the power system, suppose its unavailability probability is \( P_k \), \( X_i \) is its operating state, then the probability function of \( P(X_i) \) is:

\[
P(X_i) = \begin{cases} 
\rho_i, & \text{malfunction, } X_i = 1 \\
1 - \rho_i, & \text{running, } X_i = 0 
\end{cases}
\]

For a system that includes \( m \) elements, \( X_i = (X_{i1}, X_{i2}, ..., X_{im}) \) is a system operating state in the state space, and its joint probability distribution function \( P(X_i) \) can be determined, according to the unavailability probability and mutual relationship of each element[7]. When the failures of each component are independent of each other:

\[
P(X_i) = \prod_k P(X_{ik})
\]

2.2. Evaluation algorithm
The probability of an accident refers to the possibility that the power system will appear in this state at a certain time in the future. It is a function involving the state of all equipment in the power system,

\[
\text{Probability} = \prod_{i \in U} u(c_i) \prod_{j \in A} a(c_j)
\]

Here U is the accident equipment set, and A is the normal equipment set. \( \Omega = A \cup U \), \( \Omega \) is the complete set of all devices.

In theory, after enumerating all the states \( \Omega \) in the state space, the reliability index of the system can be calculated by the following formula:

\[
E(F) = \sum_{X_i \in \Omega} F(X_i) P(X_i)
\]

Where \( P(X_i) \) is the probability of occurrence of each system state \( X_i \in \Omega \), and \( F(X_i) \) is the calculated index function, which can represent reliability indexes such as probability, power, frequency, or time [8]. The reliability evaluation procedure is realized based on the above-mentioned algorithm principle.

2.3. Evaluation index
Probability-based reliability assessment indicators mainly have the following three types: VPRI (voltage cross-border), APRI (overload) and VSPRI (voltage stability).

The reliability index of voltage cross-border probability is:

\[
\text{VPRI} = \sum_{i \in \text{Simulated\_Situation}} \text{probability}_i \times \text{Vimpact}_i
\]

Where \( \text{Vimpact}_i \) refers to the sum of the upper and lower limit values of all node voltages caused by the i-th emergency event. The \( \text{Vimpact}_i \) unit is kV or p.u.
\[ APRI = \sum_{i \in \text{Simulated \_Situation}} \text{probability}_i \times A\text{impact}_i \]

In the formula, \( A\text{impact}_i \) refers to the sum of the overload values of all overloaded lines caused by the i-th emergency event, and the \( A\text{impact}_i \) unit is MVA or kA.

The reliability index of voltage stability probability is:

\[ VSPRI = \sum_{i \in \text{Simulated \_Situation}} \text{probability}_i \times V\text{Simact}_i \]

Where, \( V\text{Simact}_i \) is the system voltage instability caused by the i-th sudden event, which is a binary value. If an emergency event causes system voltage instability, it is \( V\text{Simact}_i \) equal to 1. Otherwise, it is \( V\text{Simact}_i \) equal to 0.

3. Risk assessment analysis

3.1. Trend situation

According to the annual grid load operation and power balance, the operation mode power flow calculation is carried out, and the heavy load in winter is considered as about 10500 MW.

The outgoing flow of the eastern Heilongjiang tie line is not more than 3,600 MW, the outgoing flow of the mid-west tie line is not more than 2000 MW, the outgoing flow of Fengda Section is not more than 2,600 MW, and the Ji-Hei outgoing flow is not more than 3,500 MW.

3.2. Risk assessment

The static scan result is shown in Figure 2.

![Figure 2](image)

Figure 2. Static scan results were reviewed

It can be seen from Figure 2 that the main problem of the static safety of Heilongjiang power grid is concentrated on the over-limit bus voltage.

3.2.1 Comprehensive analysis

Comprehensive analysis is a system-level analysis that can reveal the reliability level of the entire system. The deterministic and probabilistic comprehensive analysis results are shown in Figure 3 and Figure 4.
It can be seen from Figure 3 and Figure 4 that the main problem of the Heilongjiang power grid is concentrated on the over-limit bus voltage.

3.2.2 Failure status analysis

The various fault states of the system are sorted according to their contribution to various calculation indicators, and are visualized by bubble diagrams. Each bubble in the bubble diagram represents a fault state in the power grid. The coordinates represent the degree of influence of the corresponding fault status, the abscissa represents the probability of the fault status, and the size of the bubble represents the risk factor index of the fault status. Therefore, it can be clearly seen from the bubble chart which failure states have high impact, which failure states have high probability, and which failure states are both high, which can help planners to control high probability and high impact. The fault status is accurately located.

Deterministic and probabilistic bus voltage over-limit fault state bubble diagrams are shown in Table 1 and Table 2.

**Table 1. Deterministic bus voltage limit fault state data table**  

| Resection element | Component type | Influence value |
|-------------------|----------------|-----------------|
| Xing hei line     | Line           | 964.1558        |
| Duo yuan line     | Line           | 251.5091        |
| La ke line        | Line           | 209.3758        |
| Sui hai line      | Line           | 155.7444        |
| Ji qian jia line  | Line           | 102.7377        |
| Ta xing line      | Line           | 68.3057         |
| Xing fu transformer| Transformer   | 45.04399        |
| Sun jin line      | Line           | 31.47060        |
| Ni la line        | Line           | 26.25040        |
| Xing yuan line    | Line           | 25.18180        |
Table 2. Probabilistic bus voltage limit fault state data table

| Resection element          | Component type | Influence value | Over-limit indicator |
|---------------------------|----------------|-----------------|----------------------|
| Da he shan wind power     | Generator      | 3.89E-02        | 9.198533             |
| He ping wind power        | Generator      | 3.89E-02        | 5.21E-04             |
| Xing hei line             | Line           | 2.90E-07        | 2.79E-04             |
| Ji qian jia line          | Line           | 2.90E-07        | 2.98E-05             |
| Xing fu transformer       | Transformer    | 1.79E-07        | 1.64E-05             |
| Duo yuan line             | Line           | 4.12E-08        | 1.04E-05             |
| La ke line                | Line           | 4.12E-08        | 8.62E-06             |
| Sui hai line              | Line           | 4.12E-08        | 6.41E-06             |
| Qun xing #1 line          | Line           | 2.90E-07        | 5.94E-06             |
| Xing ta line              | Line           | 4.11E-08        | 2.81E-06             |

From Table 1 and Table 2, it can be seen that the high voltage limit indicators using the deterministic and probabilistic analysis methods are all in the Daxinganling area and Heihe area.

Deterministic and probabilistic line overload fault status data tables are shown in Table 3 and Table 4.

Table 3. Deterministic line overload fault state data table

| Resection element | Component type | Influence value | unit: MW, MVA |
|-------------------|----------------|-----------------|---------------|
| Qi he line        | Line           | 126.3205        |
| La ke line        | Line           | 107.0550        |
| Sui hai line      | Line           | 58.7746         |
| Qi min line       | Line           | 56.2950         |
| He xing line      | Line           | 54.0818         |
| Yun fang yi line  | Line           | 24.3226         |
| Yun fang jia line | Line           | 23.7693         |
| Ji bo line        | Line           | 19.2450         |
| A yuan jia line   | Line           | 18.4038         |
| A yuan yi line    | Line           | 18.3463         |

Table 4. Probabilistic line overload fault state data table

| Resection element      | Component type | Influence value | Over-limit indicator |
|------------------------|----------------|-----------------|----------------------|
| Mi shan wind power     | Generator      | 3.89E-02        | 0.1515797            |
| Qing fang jia line     | Line           | 2.90E-07        | 7.05E-06             |
| Qing fang yi line      | Line           | 2.90E-07        | 6.89E-06             |
| Qi he line             | Line           | 4.12E-08        | 5.20E-06             |
| La ke line             | Line           | 4.12E-08        | 4.41E-06             |
| Fang lin line          | Line           | 2.90E-07        | 4.00E-06             |
| Shuan ji jia line      | Line           | 2.90E-07        | 3.19E-06             |
| Qi yun jia line        | Line           | 2.90E-07        | 2.87E-06             |
| Qi yun yi line         | Line           | 2.90E-07        | 2.84E-06             |
| Sui hai line           | Line           | 4.12E-08        | 2.42E-06             |

From Table 3 and Table 4, it can be seen that the Qitaihe area and Jixi area are ranked higher by the deterministic and probabilistic analysis method. The main reason is that the regional power grid is weak. The wire diameter of the internal power supply transmission line and the regional current tie line is relatively thin, and the removal of the components can easily cause the overload of the surrounding weak lines.
Deterministic and probabilistic transformer overload fault state bubble diagrams are shown in Table 5 and Table 6.

### Table 5. Deterministic transformer overload fault state data table

| Resection element | Component type | Influence value (unit: MW, MVA) |
|-------------------|----------------|---------------------------------|
| La ke line        | Line           | 636.6636                        |
| Ni la line        | Line           | 46.3408                         |
| Xing hei line     | Line           | 29.3860                         |
| Xing fu transformer | Transformer   | 29.1980                         |
| Sun jin line      | Line           | 18.5084                         |
| Fu er #1 transformer | Transformer   | 9.0207                          |
| Fu er #2 transformer | Transformer   | 8.3029                          |

### Table 6. Probabilistic transformer overload fault state data table

| Resection element     | Component type     | Influence value (unit: Over-limit indicator) |
|-----------------------|--------------------|---------------------------------------------|
| La ke line            | Line               | 4.12E-08                                    |
| Xing hei line         | Line               | 2.90E-07                                    |
| Ni la line            | Line               | 4.12E-08                                    |
| Sun jin line          | Line               | 4.12E-08                                    |
| Xing fu transformer   | Transformer        | 6.57E-20                                    |
| Fu er #1 transformer  | Transformer        | 6.57E-20                                    |
| Fu er #2 transformer  | Transformer        | 6.57E-20                                    |

From Table 5 and Table 6, it can be seen that the deterministic and probabilistic analysis methods are used in the Daxinganling area and Heihe area, mainly due to the structural characteristics of the northern power grid.

### 4. Problems in the safety and reliability of power grids

#### 4.1. Lower ring network voltage in Daxinganling and Heihe areas

The northern power grid is affected by the characteristics of the grid structure. The power flow is mainly received through the three transmission channels of the 500 kV main transformer (500 kV Xinghei line), 220 kV Fengla line and Haibei line of the Heihe converter station. Power supply from the ring network, the current power supply in the ring network is only Daheishan Wind Farm, Nierji Water Plant, Bei’an Plant, and Jiagedaqi Plant. The power supply capacity is poor. When a component in the ring network fails, it is easy to cause a chain The fault causes the bus voltage of the substations in Daxinganling and Heihe to decrease, and the voltage is more sensitive to load changes, which affects the reliability of the power supply of the regional power grid.

#### 4.2. The wire diameter of some lines is relatively thin, which easily exceeds the thermal stability limit of the line

Some 220 kV tie lines in the eastern region have relatively small conductor diameters, and line overloads mainly occur in Jixi and Qitaihe areas. The Qihe Line, Jili Line, and Jialu Line in this area have relatively thin wire diameters. When the peripheral power supply is turned on large or fully loaded, and the peripheral lines are overhauled, it is easy to cause cascading failures and affect the reliability of the regional power grid. The Qihe Line, Qimin Line, and Huozhong Jia Line are used as the power plant's external transmission channels. The line diameter is relatively small, which limits the power output of the power plant and does not meet the line N-1 condition.

Due to the influence of the northern single ring network structure, the loads of Keshan Substation and Bei’an Substation mainly need to be transmitted through the Lak line. After the Jiagedaqi Thermal Power Plant is put into operation, most of the power flow sent from the western power grid to the
northern power grid will pass through Lak. Sending out the line will increase the flow of the Rake line, and when the neighboring line is cut off, it will cause the line to be overloaded.

The Suihai line is the main power flow transmission channel from the central network to the western network. When the Fengtun main transformer fails or the Xingfu transformer goes offline, the main transformer fails, and the Suihai line will be overloaded. Fu No. 2 Plant is the main power output source in Qiqihar area, and is responsible for the important task of supplying power to Qiqihar area and Daqing area. The tie line between it and the surrounding substations is relatively thin, because of its heavy burden, and most of them are on the same tower. Double-circuit lines are easy to disconnect at the same time, so it will bring a greater burden to other shunt lines, causing some weak lines to overload the flow.

4.3. Operation Problems of 500 kV Single Main Transformer
The 500 kV Jixian Substation, Qianjin Substation, and Hei Converter Station are operated with single main transformers, serving as the only electrical connection between the regional 220 kV and 500 kV systems, and they bear the heavy responsibility of transferring the regional surplus power to the 500 kV main network or regional power grid. Once a 500 kV line or main transformer trip accident occurs, the electromagnetic loop of the 220 kV and 500 kV main grids in the area will reduce the stability of the system, which will aggravate the tidal current of the surrounding sections.

5. Conclusion
1) For bus voltage over-limit situations, the problems are mainly concentrated in Daxinganling and Heihe areas;
2) Regarding the line overload situation, the problems are mainly concentrated in the weak lines in Qitaihe and Jixi areas, and the weak lines at power plant outlets;
3) For transformer overload, the problems are mainly concentrated in 500 kV single main transformer and 220 kV main transformer with heavy load.

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