Optimal Control Measures For Dynamic Stability Level Of Northeast Power Grid

Shi xuan LU1, Yang di SHAO2*, Peng YE3, Tian he SUN4, Xue jie WANG5, Hong peng ZHANG6, Chun shan LI7
1,2,3,4,5Shenyang Institute Of engineering, Shenyang, China
6,7Northeast Branch of State Grid Corporation of China, Shenyang, China
* Corresponding author: 1619198316@qq.com

Abstract—Due to the rapid development of new energy such as nuclear power at the transmission end of Northeast power grid, the improvement of transmission capacity of Lugu UHVDC and the large-scale development of power base, the problem of dynamic stability of Northeast Power Grid has surfaced. Based on the reality of Northeast power grid, this paper deeply and carefully carries out the dynamic stability level analysis of Northeast power grid from three aspects of source, network and load, studies the effective methods and measures to improve the damping ratio and robustness of main vibration modes between power grid regions, takes into account the scientificity, systematicness and scientificity of the measures, and provides reference for domestic and foreign related grid operation.

1. INTRODUCTION
With the rapid and vigorous development of new energy in the whole network, the continuous expansion of the interconnection scale of regional power grids and the increasingly tense relationship between energy supply and demand, the installed capacity of Liaoning Hongyanhe Nuclear Power Plant is also increasing, and the optimization of large-scale weak transmission end energy base in Northeast Power Grid continues to appear.

The dynamic stability of power grid is generally characterized by low-frequency oscillation with weak damping or even negative damping. Low frequency oscillation not only threatens the dynamic stability of large regional power grid, but also restricts the transmission capacity of long-distance transmission[1]. The research methods of low-frequency oscillation mainly include eigenvalue analysis method, time-domain simulation method and signal analysis method. Reference [2] uses eigenvalue analysis to linearize the system near the working point, form a state matrix, and analyze the sensitivity and oscillation mode of the system. If the real parts of the eigenvalues obtained by solving the equation of state are all negative, the system is stable; If there is a positive real part in the characteristic root, the system is unstable. Reference [3] uses the time-domain simulation method to calculate the complete time response of system variables by using the nonlinear equation generated by system disturbance, and obtains the damping characteristics and frequency of system oscillation mode through curve simulation. Reference [4] uses the signal analysis method to identify the oscillation mode, frequency and other information of the system mainly through the measured or simulated data, and quantitatively analyze the oscillation damping problem. Commonly used signal analysis methods include Fourier transform analysis method, wavelet analysis method, Prony method, HHT, etc.
Based on the actual operating conditions of the Northeast Power Grid and starting from the basic principles of dynamic stability, this paper mainly analyzes the impact of changes in the internal parameters of the power grid on the dynamic stability of the Hongyanhe Nuclear Power Plant after the grid-connected operation of the Hongyanhe Nuclear Power Plant, and proposes relevant measures to improve the dynamic stability of the power grid.

2. DYNAMIC STABILITY ANALYSIS MECHANISM OF POWER SYSTEM

2.1. Classification And Significance Of Power System Dynamic Stability
The dynamic stability of power system belongs to the power angle stability of power angle, voltage and frequency. It refers to that the power system can recover to the operation state before disturbance or close to the acceptable stable operation state after the action of automatic regulation and control device after small disturbance and large disturbance\(^5\). The main form of dynamic stability is low-frequency oscillation. There are two forms of low-frequency oscillation: one is interregional oscillation, which is the oscillation of one part of the system cluster relative to another part of the cluster. It involves a wide range and does great harm, and will be transmitted to the whole system through the tie line\(^6\); The second is local oscillation, which is the mutual oscillation between several generators with close electrical distance or the oscillation between other units in the system as a whole. Local oscillation is limited to the region and belongs to small-scale oscillation. It is usually manifested as the low-frequency oscillation of a single power plant through a long-distance transmission line\(^7\).

The essential reason of low frequency oscillation in power system is that some inherent oscillation frequencies of the system lack sufficient damping. The dynamic stability of the system depends on the inherent characteristics of the system and is independent of the size of the disturbance\(^8\).

2.2. Dynamic Stability Model Analysis
In the power system, taking the conventional thermal power unit as an example, the generator excitation system parameters of thermal power unit will affect the damping ratio of the system, which is affected by the generator coefficient, grid structure, installed capacity and startup mode. For a single machine infinite bus system, a fifth-order model can be used for data expression\(^9\):

\[
D = K_D K_1 K_2 K_3 K_4
\]

In the formula, \(D\) is the same damping torque coefficient; \(K_1\) is the influence of the generator's own parameters on the damping coefficient; \(K_2\) reflects the influence of the equivalent reactance of the tie line; \(K_3\) is the terminal load of the generator, which reflects the influence of the equivalent system on the local load; \(K_4\) is the influence of tie-line power on the damping coefficient.

\[
\begin{align*}
K_1 &= \frac{C_D}{2T_I} \\
K_2 &= \frac{X_D}{X_D + X_E} \\
K_3 &= \frac{1}{U_2^4 + \frac{X_D^2 X_E^2}{(X_D + X_E)^2 P_L^2}} \\
K_4 &= U_2^4 \left[ 1 - \frac{P_L^2 X_E^4}{U_2^4} - \frac{X_D X_E^2 P_L^2}{U_2^4 (X_D + X_E)} \right]
\end{align*}
\]

In the formula, \(T_I\) is the inertia time constant of the generator; \(X_D\) is the internal impedance of the isolator; \(X_E\) is the equivalent reactance between the system tie lines; \(P_L\) is the local load equivalent to...
the machine-end system; \( P_2 \) is the active power delivered by the tie line to the receiving end system; \( U_2 \) is the bus voltage of the receiving end system. Among them:

\[
C_D = U_2^2 \left[ \left( \frac{1}{X_d} - \frac{1}{X'_d} \right) T_d + \left( \frac{1}{X_q} - \frac{1}{X'_q} \right) T_q \right] + \left( \frac{1}{X'_q} - \frac{1}{X''_q} \right) \omega_0 
\]

(3)

In the formula, \( X_d, X'_d \) and \( X''_d \) are generator d-axis synchronous reactance, transient reactance and sub-transient reactance respectively; \( X_q \) and \( X'_q \) are synchronous reactance and subtransient reactance of generator q-axis respectively; \( \omega_0 \) is the rated angular velocity of the system.

The relationship between power grid dynamic stability level and system damping ratio can be found:

The damping level of the system is closely related to the reactance of the tie line. As the reactance of the tie line increases, the damping torque coefficient of the system will decrease, and the damping level of the system will also decrease. Therefore, serious low-frequency oscillation problems will occur in long-chain, weakly interconnected systems.

Along with the influence of the operation mode of the system, whenever the complexity of the system tie line increases, the damping level of the system will decrease accordingly. Therefore, the phenomenon of low frequency oscillation problems in large power grids and large systems will be more frequent.

2.3. Dynamic Stability Of Northeast Power Grid

Northeast power grid is located in Northeast China, including three provinces and one Mongolia (Heilongjiang Province, Jilin Province, Liaoning Province and Eastern Inner Mongolia).

Under the current grid structure, the main vibration mode of Northeast power grid is the oscillation mode of Southern northern cluster, that is, the oscillation mode of Liaoning and Mengdong Chifeng cluster to Heilongjiang and Mengdong Hulunbuir cluster, as shown in Figure 1.

![Northeast Power Grid Group Oscillation Mode](image)

Figure 1. Northeast Power Grid Group Oscillation Mode

If all 6 units of Hongyanhe Nuclear Power Plant are connected to the grid and put into operation, and single-phase instantaneous fault occurs in Chifeng outgoing 500 kV transmission line under full power generation mode, Chifeng unit and Liaoning unit will produce equal amplitude oscillation. Figure 3 shows the low frequency range oscillation curve of Northeast power grid.
3. ANALYSIS OF INFLUENCING FACTORS OF DYNAMIC STABILITY LEVEL

The dynamic stability level of the power grid is affected by multiple factors such as power structure, power distribution, excitation system and debugging system of power regulation, grid structure, load distribution, load type, etc. The detailed analysis is given below.

3.1. The Influence Of Different Load Types On Dynamic Stability

The load model of electromechanical simulation analysis in China is mainly based on "constant impedance and motor" mode, and the load model of Northeast Power Grid adopts 50% constant impedance + 50% motor model.

| TABLE 1. MAIN VIBRATION MODE OF NORTHEAST POWER GRID UNDER DIFFERENT CONSTANT IMPEDANCE / STATIC CHARACTERISTIC LOAD MODES |
|---------------------------------------------------------------|
| **Load/Static Characteristics Load/%** | **Oscillation Frequency/Hz** | **Damping Ratio/%** |
|------------------------------------------|-----------------------------|-------------------|
| 40                                       | 0.632                       | 8.160             |
| 50                                       | 0.632                       | 8.011             |
| 60                                       | 0.632                       | 7.876             |

Through the analysis, it can be concluded that the lower the proportion of constant impedance and the higher the proportion of motor, the higher the system damping ratio, which has a favorable impact on the dynamic stability of the system, but the impact is small. There is no dynamic instability problem under small disturbance under this oscillation mode.

3.2. Influence Of Different Load Scale On Dynamic Stability

Through the analysis of three modes of large load, waist load and small load in Northeast power grid at the end of the 14th five year plan, it is concluded that the larger the load scale, the smaller the oscillation frequency of the system and the higher the damping ratio.

| TABLE 2. MAIN VIBRATION MODES OF NORTHEAST POWER GRID UNDER DIFFERENT LOAD LEVELS |
|-----------------------------------------------|
| **Load Level /MW** | **Oscillation Frequency /Hz** | **Damping Ratio/%** |
|-------------------|-------------------------------|-------------------|
| Heavy load (69000) | 0.613                         | 8.748             |
| Lumbar load (58000) | 0.632                         | 8.011             |
| Small load (54000) | 0.641                         | 7.988             |
3.3 Influence Of Different Transmission Capacity Of Lugu DC On Dynamic Stability

Through the analysis, it can be concluded that the larger the Lugu DC transmission capacity, the lower the main vibration frequency and the higher the damping ratio of the Northeast power grid, and the oscillation center is close to the Jilin power grid side of the Liaojie section. Under this oscillation mode, there is no dynamic instability problem under small disturbance.

| Lugu DC Transmission Level /MW | Oscillation Frequency /Hz | Damping Ratio /% |
|-------------------------------|--------------------------|-----------------|
| 6100                          | 0.632                    | 8.011           |
| 8000                          | 0.625                    | 7.945           |
| 10000                         | 0.613                    | 7.763           |

3.4 Influence Of Grid Reinforcement On Dynamic Stability

Grid structure is the material basis of power transmission and the most important guarantee for system security and stability. It can be seen that the grid strengthening measures can not only improve the dynamic and stable system damping ratio, but also increase the voltage stability and frequency stability of the power grid, which is of great engineering significance.

| Grid Reinforcement                | Main Vibration Frequency /Hz | Damping Ratio /% |
|-----------------------------------|-----------------------------|-----------------|
| No reinforcement                  | 0.564                       | 5.071           |
| Strengthen Chifeng outgoing grid  | 0.566                       | 6.016           |
| Strengthen the incoming grid of load center | 0.576               | 6.217           |
| Strengthen the North–South transmission grid | 0.632               | 8.011           |

3.5 Influence Of Synchronous Power Distribution On Dynamic Stability

Based on the analysis of the different distribution positions of water, fire, and nuclear power using synchronous generators in the current Northeast power grid, it can be seen that when the synchronous generator is connected to the power base at the end of the power grid, the corresponding system damping ratio shows a downward trend; When the machine is connected to the center of the grid, the damping ratio of the system is on the rise.

| Project                                | Oscillation Frequency /Hz | Damping Ratio /% |
|----------------------------------------|--------------------------|-----------------|
| Current grid structure                 | 0.564                    | 5.071           |
| Hongyanhe Nuclear Power Plant adds 2 units | 0.543                   | 4.673           |
| Add 6 units of synchronous power supply to the grid center | 0.549               | 5.287           |

3.6 Influence Of Excitation And Speed Regulation System Parameters On Dynamic Stability

Hongyanhe Nuclear Power Plant of southern Liaoning power grid will add No. 5 and No. 6 units. At that time, the installed capacity of a single power plant will exceed 6000mw, aggravating the North–South main vibration mode of Northeast power grid.
If the current PSS and governor models and parameters are still adopted, the system damping ratio will be reduced to 2.58%, which is lower than the grid requirement of 3%.

If the active power measurement delay time of type 9 speed governing system of units 2 to 6 of Hongyanhe Nuclear Power Plant is adjusted from 0.545 s to 2.038 s, the output power range $P_{\text{max}}$ of prime mover is changed from 1.05 to 1.0; Increase the gain $K_\text{p}$ of PSS from 4 to 8; After the amplitude limit is increased from 5% to 10%; The damping ratio is increased from 2.58% to 7.02, which is the best economic and practical measure.

4. CONCLUSIONS
Based on the actual situation of Northeast power grid, this paper focuses on the research on the dynamic stability of power grid from the aspects of load model, load scale, Lugu DC transmission capacity, grid strengthening measures, power distribution, proportion of new energy, excitation of synchronous power supply and influence of excitation system, and puts forward effective measures to improve the dynamic stability performance of power grid. The following conclusions are drawn:

4.1. Give Priority To PSS And Speed Regulation System Model Parameter Optimization Measures To Improve The Dynamic Stability Of Power Grid.
The important inducement of dynamic stability of modern power system is fast excitation and speed regulation system. Therefore, optimizing and adjusting the models and parameters of Power System PSS and speed regulation system is the most economical, fastest and effective measure to improve power grid damping and dynamic stability.

4.2. Strengthening The Grid Structure Is The Most Stable Measure To Deal With The Problem Of Power Grid Dynamic Stability.
The other important inducement to the dynamic stability of modern power system is the long-distance and weak connection transmission of power. Strengthening the grid structure can significantly shorten the electrical distance of power transmission, which can not only improve the dynamic stability of power grid, but also improve the transient stability and static stability of power grid. It is the cornerstone of long-term stability of power grid development.

4.3. Strengthening The Flexibility Of Active And Reactive Power Resource Allocation Of Large-scale Weak Transmission End Energy Base Can Improve The Dynamic Stability Of Power Grid.
Large scale weak transmission end energy base will inevitably aggravate the dynamic stability of power grid. In addition to relying on the long-term network architecture, it is necessary to improve the dynamic voltage stability and frequency stability of the power base transmission system and improve the damping characteristics of the system from the power side.

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