Research on Assistant Decision of Transient Stability Based on Trajectory Sensitivity

Kaijin Xue¹, Ye Tang², Chen Wang², Ziyang Liu³, Yan Zhao³, and Donglai Wang³,*

¹State Grid Liaoning Information and Communication Company, Shenyang, Liaoning 110006, China
²State Grid Liaoning Marketing Service Center, Shenyang, Liaoning 110006, China
³School of Renewable Energy, Shenyang Institute of Engineering, Shenyang, Liaoning 110136, China

Abstract. In order to improve the execution rate of the power system dispatch plan, a dispatch plan assisted decision-making considering transient safety and stability constraints is proposed. First, the principles for formulating power system transient stability control scheduling are given. Then, through the topological analysis of the expected fault location, decouple the unstable faults, formulate appropriate multi-fault adjustment timing according to the severity of the fault, and decompose the prevention and control problems of multiple fault constraints into several single fault stable control decision problems. In the end, a preventive control adjustment strategy that satisfies all transient stability constraints is obtained. Combined with parallel computing technology, the algorithm has the feasibility of online application.

1 Introduction

During the transition period of UHV AC-DC interconnected power grid [1-3] construction, due to the high and low voltage electromagnetic ring network structure and the relatively weak connection of the local power grid, transient stability damage accidents are prone to occur. Auxiliary decision-making is aimed at all the safety and stability problems existing under a certain power flow section, and provides dispatch operators with a total solution proposal to change the current grid operation point [4,5]. Compared with emergency control, preventive control can form an executable control plan before the failure occurs, and the control cost is small. Therefore, it is of great practical significance to study the problem of transient stability prevention and control.

Transient stability assisted decision-making according to the calculation conclusion of the transient stability analysis of the power grid, for the hidden dangers that endanger the safety of the system, the correlation coefficients of the adjustable amount of the system and the dangerous amount of the system are calculated [6-9]. The order of the adjustment components is obtained by ranking the correlation coefficient and the adjustment range, to obtain the adjustment method to ensure the stability of the power grid and the minimum control cost. This paper proposes a parallel calculation method for prevention and control using fault adjustment timing analysis and dynamic sensitivity analysis [10,11]. On the technical route, time-domain simulation based on fine modeling, using parallel computing technology, the calculation results fully meet the requirements of online applications.
2 Track sensitivity

2.1 Principles of track sensitivity

Trajectory sensitivity analysis quantitatively analyzes the influence of the factors on dynamic quality by studying the sensitivity of the dynamic response of the dynamic system to certain parameters or initial conditions or even the system model. Trajectory sensitivity can calculate the sensitivity along the system running trajectory and the sensitivity of parameters to the dynamic response. By linearizing the system model at various points of the system trajectory, the system trajectory changes can be directly determined when the system initial conditions and parameters change slightly.

The dynamic behavior of the power system can generally be expressed by the differential-algebraic equations model shown in (1) and (2).

\[
\dot{x} = f(x, y, \alpha)x(t_0) = x_0 \quad (1)
\]

\[
0 = g(x, y) \quad y(t_0) = y_0 \quad (2)
\]

where \( x \) represents the vector composed of the state variables of the generator and its regulation system, \( y \) represents the algebraic variable vector, \( \alpha \) is the system parameter vector, \( t_0 \) is the initial moment, \( x_0 \) and \( y_0 \) is the initial value of \( x \) and \( y \), respectively.

The trajectory sensitivity can reflect the degree of influence of parameter changes at any time on the stability of the system. The two sides of the system model equations (1) and (2) are used to differentiate the control variables, and the trajectory equations of the sensitivity are obtained as equations (3) to (6), as shown below.

\[
\dot{x}_\alpha = \left[ \frac{\partial f}{\partial x} \right] x + \left[ \frac{\partial f}{\partial y} \right] y + \left[ \frac{\partial f}{\partial \alpha} \right] \alpha \quad (3)
\]

\[
0 = \left[ \frac{\partial g}{\partial x} \right] x + \left[ \frac{\partial g}{\partial y} \right] y + \left[ \frac{\partial g}{\partial \alpha} \right] \alpha \quad (4)
\]

\[
x_\alpha(t_0) = 0 \quad (5)
\]

\[
y_\alpha(t_0) = \left. \left[ \frac{\partial g}{\partial \alpha} \right] \right|_{t=t_0}^{-1} \quad (6)
\]

In the formulas, \( \frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}, \frac{\partial g}{\partial x}, \frac{\partial g}{\partial y} \) are time-varying matrices that change with the running trajectory of the system; \( \frac{\partial x}{\partial \alpha} = \dot{\delta}_x/\dot{\delta} \) \( \alpha \) and \( \frac{\partial y}{\partial \alpha} = \dot{\delta}_y/\dot{\delta} \alpha \) represent the sensitive trajectories of the system state variables and algebraic variables to the parameter vector, respectively.

2.2 Division of generators

According to the simulation results of temporary stability after failure, generators are generally divided into critical and non-critical machines. The division principle of critical machine and non-critical machine is recorded as fault removal time, set an observation time, and the time is set as the 18th cycle after fault removal. Three types of generator division indicators have been adopted successively. The definition indicators for each generator are as follows:

Index 1 is shown in equation (7).

\[
AVID_{ii} = \sum_{t=t_0}^{t_\text{end}} \left| \delta_{i \_ \text{col}}(t + \Delta t) - \delta_{i \_ \text{col}}(t) \right| \quad (7)
\]
where $\Delta t$ is the integration step, which $\delta_{i, \text{coi}}(t)$ is the rotor angle of the generator at the COI coordinate at time $t$.

Index 2 is shown in equation (8).

$$AVI_{2i} = (\delta_{si} - \delta_{ci}) - \sum_{i=1}^{N_G} (\delta_{si} - \delta_{ci}) / N_G \tag{8}$$

The positive values of $AVI_{2i}$ are sorted from large to small to determine the maximum $AVI_{2i}$ value gap. The generator above this gap constitutes the leading cluster $S_g$ and the generators below constitute the remaining cluster $A_g$.

Both $AVI_1$ and $AVI_2$ are indicators for measuring the change in power angle, and represent the amount of change in power angle relative to the mean value of power angle for a period of time after the fault is removed.

Index 3 specifies the rotation angle of each generator at the specified time.

The simulation calculation proves that the division results of the critical machine group and the non-critical machine group obtained according to the above three indicators are consistent, and any one of them can be selected.

### 2.3 Selection of generator

The adjustment objects include all critical generators and some non-critical machines, as shown in equation (9).

$$\alpha = [P_1 \cdots P_m P_{m+1} \cdots P_{m+n}]^T \tag{9}$$

The selection of some non-critical machines follows the principle shown in Fig. 1.

![Figure 1. Schematic diagram of generator selection.](image)

As shown in (10) to (12), the generators related to the fault line are searched layer by layer until the sum of the adjustable capacities of the generators to be adjusted is equal to or slightly greater than the transmission power lost due to fault removal.

$$Z_{ia} < Z_{ib} < \ldots < Z_{ie} < Z_{if} \tag{10}$$

$$\sum_{l=a}^{e} (P_{g\text{Max}} - P_{gl}) < P_{ij} \tag{11}$$

$$\sum_{l=a}^{e} (P_{g\text{Max}} - P_{gl}) + (P_{g\text{Max}} - P_{gl}) \geq P_{ij} \tag{12}$$

In the formula, $Z_{ij}$ represents the impedance value between nodes $i$ and $j$, $P_{g\text{Max}}$ represents the upper limit of the generator's active power output, $P_g$ represents the actual active power output of the generator, and $P_{ij}$ represents the transmission power lost due to the line break caused by the fault.
3 Aided decision-making based on trajectory sensitivity

In the calculation of transient stability, the relative power angle difference of the generator is used as the basis for judging stability. When the relative power angle difference of the generator is greater than 50 degrees, the system becomes unstable. Definition $\delta_{ml}$ is the maximum power angle difference at the moment of system instability, $m$ corresponds to the maximum power angle bus, and $l$ corresponds to the minimum power angle bus. $\delta_{ml}$ is used as an indicator to measure the dynamic performance of the system, and $p_i$ is the active output of each generator to be adjusted. By calculating the trajectory sensitivity $\partial \delta_{ml} / \partial P_i$, it is possible to determine the generators and their degree of correlation that are closely related to the change in maximum power angle difference, and then by adjusting the output of these generators, the stability of the system is improved. The calculation process of scheduling assistant decision is as follows:

Step 1: Determine the range of objects to be adjusted, such as generator, load, etc.;

Step 2: Determine the initial adjustment total, and use the line loss flow caused by the fault as the initial adjustment total value $P_{s0}$.

Step 3: Calculate the trajectory sensitivity of the generator to be tuned to the maximum relative power angle according to the calculation results of the dynamic safety assessment stage and equations (2) to (5).

Step 4: Obtain the maximum value of the trajectory sensitivity of each machine, and calculate the adjustment weight and adjustment amount of each machine.

\[
\alpha_i = \max \left( \frac{\partial \delta_{ml}}{\partial P_i} \right) \frac{1}{\sum_{i=1}^{n} \max \left( \frac{\partial \delta_{ml}}{\partial P_i} \right)} \quad (13)
\]

\[\Delta P_{ij} = \alpha_i \Delta P_{ij} \quad i = 1, ..., p \quad j = 1, ..., m \quad (14)\]

Step 5: Based on the above adjustment results, perform power flow check and temporary stability calculation check.

Step 6: If the initial adjustment amount satisfies the above-mentioned check, then reduce the amount of mediation one by one according to the proportion.

\[\Delta P_{sj} = k_j \Delta P_{s0}, \quad k_j \in (0,1), \quad j = 1, ..., m \quad (15)\]

Step 7: Return to Step 4 until the minimum adjustment amount and each adjustment component are found.

In the process of determining the minimum adjustment amount, when the single machine is serially executed, the dichotomy method is adopted, and the calculation process is shown in Fig. 2.

![Figure 2. Scheduling assisted decision-making process of serial binary calculation.](Image)
4 Parallelization of scheduling assistant decision

The distributed parallel computing platform is mainly composed of management nodes and computing nodes. The management node is responsible for communication and collaboration between various calculations. The calculation node is responsible for completing the calculation tasks distributed by the management node and transmitting the calculation results back to the management node.

When the prevention control is executed in parallel, for the calculation example judged as insufficient safety margin in the dynamic safety assessment stage, the management node sends the calculation result to the calculation node, and calculates the adjustment result on each calculation node. After the calculation is completed, the result is uploaded to management node. The management node is responsible for comparing the adjustment results of each gear, and outputs the minimum adjustment total amount to ensure the stability of the system and the specific adjustment amount of each generator.

5 Conclusion

The auxiliary control strategy for power system transient stability proposed in this paper adopts the topology analysis of instability fault network, determines the adjustment timing according to the severity of the fault, decouples the instability fault, and decouples the prevention and control problems of multiple fault constraints into multiple single-fault stable control decision problem. According to the fault adjustment sequence, the control strategy is calculated in sequence. For the same level of faults, the parallel calculation technology can quickly form the best plan to ensure the safe operation of the power grid, and provide rapid and effective decision support for dispatching and command to realize online calculation.

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