Research on simulation technology of power system operation and dispatch control based on trend tracking

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Abstract. Over the past decade, Chinese energy structure and power system technology have undergone tremendous changes. First, the proportion of new energy in power generation capacity is increasing, and the permeability of some areas has reached 30% - 50% of the total power generation capacity; second, the characteristic of power electronics in power system is becoming more and more obvious. The impact of these two aspects on the power system is that the power fluctuation of the power grid is intensified, and the power flow is flexible and changeable, which brings new challenges to the operation scheduling and simulation technology of the power system. Therefore, based on Power System Analysis Synthesis Program (PSASP) electromechanical transient simulation program, this paper studies and proposes a power grid regulation and control analysis method, it can help the dispatchers and operators to improve the dispatching plan and the accuracy of various kinds of anticipated faults. This method seeks to simulate the power flow fluctuation of the real power grid approximately. The validity of the proposed method is verified by the simulation calculation of some year national interconnection data.

1. Introduction

Over the past 30 years, Chinese smart grid dispatching and control system has gone through three stages [1-3]: the first stage is digestion and absorption, the urgent need for dispatching technology support at all levels is solved; the second stage is development and innovation, the needs of dispatching and control at the initial stage of national interconnection is met; the third stage is catching up with the advanced stage, the construction of a world-class strong smart grid dispatching agency is supported.

With the increasing scale of Chinese power grid, various large-scale renewable energy is connected to the power grid [4-5], the structure is becoming more and more complex, and the uncertainty of operation mode increases, which brings new challenges to power system operation scheduling and simulation technology [6-7].

At present, the automatic dispatching system [8-12] is widely used in Chinese power grid, which basically realizes the automatic collection of power grid operation data [13]. It provides an opportunity for the formulation of power grid dispatching plans at various time scales. Extracting effective information from dispatching plan and actual operation data and formulating a shorter time scale operation mode can realize the verification and revision of short-term dispatching plan and the analysis of actual operation data.
Existing simulation software, such as PSASP, BPA and so on, are based on an initial power flow state to study the system response under locally given anticipated faults, hidden in the simulation process is that most of the system is not impacted by any external interference, but the actual operation of the power grid is not the case. Therefore, it is urgent to develop new technical means to simulate the fluctuation of power flow in real power grids and to consider the trend of generation and load change (such as rapid load growth, new energy power change, etc.). Therefore, this paper presents a method of power grid regulation and control analysis based on electromechanical transient quasi-steady state simulation. Based on the PSASP electromechanical transient simulation program, this method transforms the difference of generator and load power in the grid control planning point into the disturbance of the slow change of the system, simulates the fluctuation of the real power flow, and simulates all kinds of anticipated faults on this basis, so as to help the dispatchers of the power grid to improve the dispatching plan and improve the accuracy of the verification of all kinds of anticipated faults.

2. Data source
Data are integrated by the Dynamic Security Assessment (DSA) project team of the China electric power research institute. The data of the whole network are integrated and sent to the PSASP electromechanical transient program analysis platform together with the grid planning points, as shown in Figure 1. DSA downloads online data for various checks. PSASP obtains on-line data from DSA and daily generation and load schedule, then PSASP forms various operation modes which can be checked by DSA through electromechanical transient trend tracking. At the same time, PSASP can modify the data of Japanese generator and load plan through electromechanical transient trend tracking.

![Figure 1. Data source diagram.](image)

3. Method principle and specific processing

3.1. Basic principles and trend tracking process
From the point of view of quasi-steady-state time-domain simulation calculation, the method proposed in this paper converts a series of problems of solving power flow non-linear equations into the problem of obtaining stable operating state points of the system by time domain simulation under relatively small slow disturbances [14-17]. Specifically, the method is based on the starting point of each grid dispatching plan point, in the time domain simulation calculation, a series of special settings are used to simulate the transition process of generator and load power changes between different planning points, the new stable operation point of the system after slow disturbance corresponds to a power grid dispatching plan point.

Based on this method, the process of intelligent assistant formulation and verification of power grid dispatching plan is designed by combining PSASP modules such as power flow, transient stability calculation and static security analysis, as shown in Figure 2. Using this method, the power grid dispatching plan maker can get more detailed grid dispatching schedule and security checking information at all points.
(1) Downloading online data and power generation and load daily plan and determining the starting point of trend simulation.

(2) Obtaining the power change information of generation load at the next time point.

(3) Adjusting the plan point according to the instructions, if not, transferring to step (4);

(4) Conversion of various state change information;

(5) PSASP electromechanical transient trend tracking.

Using the above planning point as the starting point, the target planning point is tracked by quasi-steady state simulation;

(6) If the system is unstable, step 3 is adopted to readjust the power of the generating and load; if the system is stable, the trajectory of mode change is preserved.

(7) Selecting the typical plan points in (6) and whether to check. If the check is carried out, step (8) will be transferred, if not, step (10) will be transferred;

(8) Parallel computing is adopted to check the safety of the selected planning points, checks are performed through DSA;

(9) Synchronizing with step (7), whether there is another scheduling point, and if there is one, turn to step (3), if not, turn to step (10);

(10) Outputting complete and updated power grid dispatching schedule and security checking information at all points.

Figure 2. Assisted scheduling planning and checking process based on trend tracking.
3.2. Tracking power change of generator
Generators in the grid mainly include synchronous generators, wind turbines, and very few photovoltaic power stations. The method in this paper mainly traces the active power of synchronous generators and wind turbines. Reactive power scheduling is not involved in actual power grid dispatching planning. The active power tracking method of synchronous generator is as follows: ignoring the stator loss of the generator, the active power at the initial point is inferior to the planned active power at the target point to calculate the mechanical power at each simulation time, thus a mechanical power operation curve is formed in the PSASP transient stability program to enable the generator to generate electricity at a specified power level, when the difference between the generator and the target power reaches a certain range, the original governor model of the generator is restored, Figure 3 is the transfer function block diagram of the general speed governor model of type 1 in PSASP [17]; the reactive power of synchronous generator is not processed, and the voltage regulator is used to keep the stator terminal voltage constant, Figure 4 is the block diagram of transfer function of PSASP model 1 regulator [17]; the active power of wind turbines is changed by changing the wind speed, according to the difference between the current point power and the target point power, the power at each moment is calculated and the wind speed is deduced from the power, Formula (1) is the relationship between wind speed and power in PSASP (\( \rho \) is the air density (kg/m\(^3\)); \( V_w \) is the abbreviation of the wind speed; \( A_r = \pi R_e^2 \) is the abbreviation of the sweeping area of the wind turbine blade, \( R_e \) is the radius (m); \( V_{in} \) and \( V_{out} \) are the abbreviation of the wind turbine cut-in speed and cut-out speed respectively; \( C_p \) is the abbreviation of the wind energy utilization coefficient of the wind turbine, that is, the ratio of wind energy absorbed by the wind turbine per unit time to all wind energy passing through the blade rotating surface) [17]. The reactive power control mode of wind turbine is constant voltage control.

\[
\begin{align*}
\omega_p &= K_i \omega \sum \varepsilon + \frac{1}{2} K_0 \varepsilon^2 \\
\sigma &= \frac{1}{\mu_{\text{max}}} \left( 1 - \frac{S_{\text{th}}}{S_{\text{th}0}} \right) K_{\text{act}} \\
K_{\text{act}} &= \frac{1}{1 + S_{\text{T}} K_{\text{i}}} \\
\alpha &= \frac{P_1 - P_2}{P_1} \\
1 - \alpha &= \frac{P_1}{P_{12}} \\
\end{align*}
\]

\[
\begin{align*}
\varepsilon &= \frac{1}{2} K_0 \omega \varepsilon^2 \\
\sigma &= \frac{1}{\mu_{\text{max}}} \left( 1 - \frac{S_{\text{th}}}{S_{\text{th}0}} \right) \\
K_{\text{act}} &= \frac{1}{1 + S_{\text{T}} K_{\text{i}}} \\
\alpha &= \frac{P_1 - P_2}{P_1} \\
1 - \alpha &= \frac{P_1}{P_{12}} \\
\end{align*}
\]

Figure 3. Transfer function block diagram of PSASP type 1 governor.

\[
\begin{align*}
\sum V_{f0} + V_f &= K_{\text{a}} \frac{1}{1 + S_{\text{T}} K_{\text{i}}} + V_{s} \\
K_{\text{a}} &= \frac{1}{1 + S_{\text{T}} K_{\text{i}}} \\
E_{\text{fd}} &= \frac{1}{1 + S_{\text{T}} E_{\text{f}}} \\
E_{\text{fd}0} &= \frac{1}{1 + S_{\text{T}} E_{\text{f0}}} \\
E_{\text{fd}max} &= \frac{1}{1 + S_{\text{T}} E_{\text{fmax}}} \\
\end{align*}
\]

\[
\begin{align*}
\sum V_{f0} + V_f &= K_{\text{a}} \frac{1}{1 + S_{\text{T}} K_{\text{i}}} + V_{s} \\
K_{\text{a}} &= \frac{1}{1 + S_{\text{T}} K_{\text{i}}} \\
E_{\text{fd}} &= \frac{1}{1 + S_{\text{T}} E_{\text{f}}} \\
E_{\text{fd}0} &= \frac{1}{1 + S_{\text{T}} E_{\text{f0}}} \\
E_{\text{fd}max} &= \frac{1}{1 + S_{\text{T}} E_{\text{fmax}}} \\
\end{align*}
\]

Figure 4. Transfer function block diagram of PSASP type 1 voltage regulator.
3.3. Tracking power change of generator

Most load models in power grid are hybrid models of induction motor and constant impedance. In planning simulation, the load model with variable initial and target power is replaced by the constant power load model, the variation of power is also constant power load. The difference of active power and reactive power between the initial point and the target point is calculated respectively. The variation of load active power and reactive power at each simulation time is calculated, and the curve of load active power and reactive power is formed, the PSASP load variation disturbance (as shown in Figure 5) is used to track the load power dynamically. When the load power reaches a certain range of the target power, the original load model is restored.

\[
P = \begin{cases} 
0 & \text{if } V_w \leq V_{in} \\
\frac{P}{2} A_r V_w^3 C_p & \text{if } V_{in} \leq V_w \leq V_{out} \\
0 & \text{if } V_{out} \leq V_w
\end{cases}
\]  

(1)

3.4. Method effectiveness testing

Some year North China-Central China networking data is selected to check the method proposed, the basic information of this data is: 6600 AC lines, 8718 transformers, 1678 generators and 6718 loads. A simple 20-minute power grid dispatching plan is formulated. The power change mainly involves 100 generators. Using the method in Section 3.1, according to the given day plan generator table, two points are selected to track, and the change of generator output is transformed into the change curve of mechanical power. The output of generator is tracked by trend simulation, and the terminal voltage of generator is regulated by its own voltage regulator.

From the initial point to the planned point, the quasi-steady state simulation is carried out using the proposed method to track. Generators with the greatest errors are listed in Table 1 (error percentage = absolute value of difference between the calculated value and the planned point value divided by the
planned point value). From Table 1, it can be seen that the proposed algorithm can approach the next planning point from the trend of the initial planning point within a small error range (the maximum error of this example is 2.39%). All the operation information of the grid corresponding to the planning point can be obtained.

Table 1. Generator power error information.

| Generator | Percentage of active error |
|-----------|-----------------------------|
| G1        | 2.39%                       |
| G2        | 2.37%                       |
| G3        | 2.30%                       |
| G4        | 2.29%                       |
| G5        | 2.27%                       |
| G6        | 2.26%                       |
| G7        | 2.21%                       |
| G8        | 2.18%                       |
| G9        | 2.16%                       |
| G10       | 2.08%                       |

4. Visual display
The visualization display is based on the electromechanical-electromagnetic hybrid sand table deduction and decision support system of China Electric Power Research Institute. A variety of visualization and interaction technologies have been integrated into the electromechanical-electromagnetic hybrid sand table deduction and decision support system, including: (1) Three-dimensional graphics technology. (2) Three-dimensional rendering technology. (3) Three-dimensional animation technology. (4) Conventional graphics and animation technology.

5. Conclusions
Based on Power System Analysis Synthesis Program electromechanical transient simulation program, this paper studies and proposes a power grid regulation and control analysis method based on electromechanical transient quasi-steady state simulation, it can make the dispatchers and operators fully understand the internal characteristics of the corresponding dispatching planning points and the transition process between points, and on this basis, all kinds of anticipated fault sets will be simulated, thus it can help the dispatchers and operators to improve the dispatching plan and the accuracy of various kinds of anticipated faults. This method seeks to simulate the power flow fluctuation of the real power grid approximately. The validity of the proposed method is verified by the simulation calculation of some year national interconnection data.
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