Large-scale source-grid-load friendly interactive system introduction and real load shedding verification test technology

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Abstract: On the basis of briefly analysing the construction background, systemic function, and practice situation of large-scale source-grid-load friendly interactive system and introducing real load shedding verification of the system, this paper proposed an effective strategy validation technique based on preset instruction release mode, a time test method of real load shedding control command transmission according to global GPS clock synchronisation technology, and a frequency measurement method according to zero-crossing detection and digital filter technology. These methods can accurately measure the system's control time and dynamic frequency on real load shedding. The real experimental results verified that quick load shedding time and frequency control effect when DC-blocking fault happens meet system expectations. It effectively verified the function design of large-scale source-grid-load friendly interactive system.

1 Introduction

The introduction of UHV power grid into the Jiangsu province and the large-scale consumption of renewable clean energy are changing the existing structure of Jiangsu power grid. The operation characteristics of the power grid have also undergone fundamental changes and gradually formed a large receiving-end grid. As the equivalent inertia and the capacity of stabilising regulation of the generator in the regional power grid are being weakened, the stability problems such as frequency, power angle, and voltage caused by multi-DC bipolar blocking or commutation power supply to the uncontrollable load are increasingly prominent. When the power supply interaction between power grid and power supply and load, finally effective strategy validation technique based on preset instruction release mode, a time test method of real load shedding side). After the fault, the system frequency dropped rapidly, and the frequency reached the minimum of 49.563 Hz after 12s (21:58:15), the frequency curve is shown in Fig. 1.

The overall strategy of the source-grid-load system is shown in Fig. 2. The emergency response of UHV failures is divided into four phases: state perception, optimisation decision, coordinated control, and orderly recovery. Set up disposal strategies separately. Load control is divided into three modes: the millisecond emergency automatic control mode, the second-level less emergency automatic control mode, the minutes of auxiliary decisions and manual confirmation of the conventional control mode. According to the operation status of the power grid, the three modes all play their roles in succession according to the unified strategy to achieve different control objectives. Accident handling is divided into four steps: first, when the system frequency decline is large in a short-term, to accept the instructions of East China Grid frequency emergency coordination control system and cut-off part of the interruptible load in millisecond, while the unit primary frequency modulation increases output automatically and rapidly to reduce system frequency drop. Second, adding output automatically and quickly to reduce the power shortage through the function of the unit AGC, to restore the frequency to a stable value; Third, if the power flow exceeding the limit, the system is insufficient or contact line power is still overuse, part of interruptible load should continue to be cut-off; Fourth, if the interruptible load capacity is insufficient, to take the scheduling load batch control as a backup means.

The source-grid-load system is a quick and effective method of load shedding in the case of a large power grid failure. As an application innovation of load control, it can play more positive roles in preventing large-scale blackouts and over-exceeding of power flow caused by fluctuations of power grid frequency. Through the system real load shedding verification, the design features and the speediness of load shedding or other effects can be identified more realistic.

2 General situation of the real load shedding verification

In order to verify the overall function of East China Power Grid frequency emergency coordination control system and to cope with the frequency control effect under a large power grid shortage of short-term emergency, the function of system protection fast load shedding of Jiangsu ‘Source-Grid-Load System’ was as an integral part of East China Frequency Emergency Coordination Control System linkage, to participate in Jin-Su UHVDC blocking system verification.

Fig. 1 Frequency curve of ‘09-19’ Jin-Su DC blocking fault

Fig. 2 The emergency response of UHV failures is divided into four phases: state perception, optimisation decision, coordinated control, and orderly recovery. Set up disposal strategies separately. Load control is divided into three modes: the millisecond emergency automatic control mode, the second-level less emergency automatic control mode, the minutes of auxiliary decisions and manual confirmation of the conventional control mode. According to the operation status of the power grid, the three modes all play their roles in succession according to the unified strategy to achieve different control objectives. Accident handling is divided into four steps: first, when the system frequency decline is large in a short-term, to accept the instructions of East China Grid frequency emergency coordination control system and cut-off part of the interruptible load in millisecond, while the unit primary frequency modulation increases output automatically and rapidly to reduce system frequency drop. Second, adding output automatically and quickly to reduce the power shortage through the function of the unit AGC, to restore the frequency to a stable value; Third, if the power flow exceeding the limit, the system is insufficient or contact line power is still overuse, part of interruptible load should continue to be cut-off; Fourth, if the interruptible load capacity is insufficient, to take the scheduling load batch control as a backup means.
impact test, and verify the real load shedding function verification on 24 May 2017.

2.1 Purpose of real load shedding verification

Coordinated with the overall functional test of East China Power Grid frequency emergency coordination control system, the purpose of real load shedding verification is to verify the source-grid-load control strategy and implementation performance when UHVDC bipolar blocking and other serious faults happen.

i. To verify the source network load system to receive the East China Frequency Emergency Coordination Control System instructions, load removal and recovery control strategy, and the correctness of the implementation effect.

ii. To test source-grid-load system's entire group action response time of real load shedding through the 2M dedicated line and wireless 4G private network.

iii. To optimise the cooperation strategies among subsystems and improve the overall system performance.

2.2 Content of real load shedding verification

The real load shedding verification of the source-grid-load system is to receive the control instructions of the East China frequency coordinated control system in the emergency situation of Jin-Su UHVDC blocking and system impact to complete the rapid cutting off of the interruptible load so as to verify the system instruction execution, control strategy, terminal operation and load recovery correctness. The entire group of removal time test should be carried out for different access types of users (2M dedicated line and wireless 4G).

Before the overall function test, the channel status, all devices, grid-load interactive terminal pressure boards status and the devices setting value between the Dispatching Master Station, Mu-Du Central Station, Mu-Du Sub-Station, Tai-Cang Sub-Station, Yu-Shan Sub-Station, Wu-Jiang Sub-Station, and grid-load interactive terminal should be checked, and the real load shedding verification should be carried out in normal operating status.

The control strategy is determined according to the load-shedding capacity issued by East China Association of Control and Grid-load control strategy and implementation performance when UHVDC bipolar blocking and other serious faults happen.

2.3 Situation of real load-shedding verification

Before the real load-shedding verification test, East China's total load is 170 GW, Jiangsu Province's total load is 64.150 MW, Suzhou's total load is 17.510 MW, the whole grid frequency is 50.00 Hz, Jin-Su DC power is 3030 MW, Fu-Feng DC power is 2536 MW, Bin-Jin DC power is 2483 MW, Ling-Shao DC power is 1922 MW, Long-Feng DC power is 970 MW, Ge-Nan DC power is 740 MW, Yi-Hua DC power is 1807 MW, Lin-Feng DC power is 883 MW.

2.4 Effect of real load shedding verification

At 14:04:57, on May 24, the test began, manually triggered Suzhou converter station DC-blocking fault. The seven UHV DC in the East China region in addition to Jin-Su UHV are all involved in the DC power upgrade, removing seven pumping units in East China (Ban-Ling, Xian-Ju, Tian-Huangping, Tong-Bai, Yi-Xing, Xiang-Shuijian, Lang-Yashan pumped storage power plant each 1), and actually remove part of the real-time interruptible load in Suzhou. Among them, after Jin-Su DC-blocking fault, the other DC power raise total amount is 680 MW, and the cut-off power of pumped storage power station is 3020 MW. Source-grid-load system in Suzhou millisecond real-time interruptible load (maximum capacity is 1100 MW) are all involved in the actual verification.

East China Frequency Control System issued the total load-shedding capacity of 260 MW to Jiangsu, and Mu-Du Central Station actually released to cut-off interruptible load capacity is 260 MW, both of them are the first level, cutting off 233 users, with the actual removal power of 260 MW. In real load-shedding process, the central station, substation, near-substation to grid-load interactive terminal signal are normal, the action is performed correctly. After the control system action, the whole grid frequency fluctuation is within the expected range, and the source-grid-load system has a significant effect on stabilising the grid frequency. At 14:20, 80% interruptible load users resume load based on the load recovery prompts under the guidance of site personnel. At 14:30, all the load recovered. At 16:55, Jin-Su DC bipolar recovered operation.

Before and after the test, the important section of southern Jiangsu tidal current distribution is shown in Table 1. Due to the DC blocking of Jin-Su, there is a large loss of power in the DC links location in southern Jiangsu, causing the southern section of the relevant transmission section power increases, but did not exceed the limit.
In order to ensure the smooth progress of the real load-shedding verification, the correctness of the system communication link and the strategy execution needs to be verified in advance, and proposed an effective strategy validation technique based on preset instruction release mode. Setting the preset mode in the system, only to send a load cutting instruction to the test bit from the centre station without action, but a preset return. The starting condition is that the central station inputs the drive test board, exits the total function board, and the preset option is enabled. The command sent is the preset command. The system real load-shedding verification content is shown in Fig. 3.

To meet the test of strategy verification, central station, substation, terminal were all set soft or hard board, the logic shown in Fig. 4. Among them, the central station hard board includes a total functional board and load recovery board; substation includes the overall function hard board and channel hard board, soft board includes channel soft board and load recovery soft board; grid-load interactive terminal includes cutting load fast cutting soft board, precision cut load soft closing board, the user switch shunt hard board, the user shunt switch closing board. Table 2 shows the state of the various stages.

### Table 1 Power flow of important sections before and after real load shedding (ten thousand kilowatt)

<table>
<thead>
<tr>
<th>Section</th>
<th>Stable quota</th>
<th>Tide before the test</th>
<th>Tide after the test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meili-Mudu double line</td>
<td>3000</td>
<td>1020</td>
<td>2390</td>
</tr>
<tr>
<td>Doushan-Changshunan line</td>
<td>2000</td>
<td>840</td>
<td>1320</td>
</tr>
<tr>
<td>Luqiao- Changshunan single line</td>
<td>800</td>
<td>180</td>
<td>370</td>
</tr>
<tr>
<td>Dongwu-Shipai 5681 single line</td>
<td>1350</td>
<td>450</td>
<td>1070</td>
</tr>
<tr>
<td>Jiangdu-jinling 5291 single line</td>
<td>2000</td>
<td>1360</td>
<td>1330</td>
</tr>
<tr>
<td>Taixing-Doushan double line</td>
<td>2800</td>
<td>1730</td>
<td>2230</td>
</tr>
</tbody>
</table>

### Fig. 3 System test framework of real load shedding

### Table 2 Table of board state at each test stage

<table>
<thead>
<tr>
<th>Board</th>
<th>Location</th>
<th>Before the test</th>
<th>Simulation test</th>
<th>Real test</th>
</tr>
</thead>
<tbody>
<tr>
<td>the overall function hard board</td>
<td>central station</td>
<td>off</td>
<td>on</td>
<td>on</td>
</tr>
<tr>
<td>load recovery hard board</td>
<td>central station</td>
<td>off</td>
<td>on</td>
<td>on</td>
</tr>
<tr>
<td>the overall function of the hard board</td>
<td>substation</td>
<td>off</td>
<td>on</td>
<td>on</td>
</tr>
<tr>
<td>channel hard board</td>
<td>substation</td>
<td>on</td>
<td>on</td>
<td>on</td>
</tr>
<tr>
<td>channel into soft board</td>
<td>substation</td>
<td>off</td>
<td>on</td>
<td>on</td>
</tr>
<tr>
<td>load recovery soft board</td>
<td>substation</td>
<td>off</td>
<td>off</td>
<td>off</td>
</tr>
<tr>
<td>fast cut soft board</td>
<td>participation terminal</td>
<td>off</td>
<td>on</td>
<td>on</td>
</tr>
<tr>
<td>closing soft board</td>
<td>participation terminal</td>
<td>off</td>
<td>off</td>
<td>off</td>
</tr>
<tr>
<td>trip hard board</td>
<td>participation terminal</td>
<td>on</td>
<td>on</td>
<td>on</td>
</tr>
<tr>
<td>closing hard board</td>
<td>participation terminal</td>
<td>off</td>
<td>off</td>
<td>off</td>
</tr>
</tbody>
</table>

### Fig. 4 System board setting logic diagram

### 3 Effective strategy validation technique based on preset instruction release mode

In order to ensure the smooth progress of the real load-shedding verification, the correctness of the system communication link and the strategy execution needs to be verified in advance, and proposed an effective strategy validation technique based on preset instruction release mode. Setting the preset mode in the system, only to send a load cutting instruction to the test bit from the centre station without action, but a preset return. The starting condition is that the central station inputs the drive test board, exits the total function board, and the preset option is enabled. The command sent is the preset command. The system real load-shedding verification content is shown in Fig. 3.

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### 4 Time testing technology based on global GPS clock synchronisation

Aimed at real load-shedding verification, the control command transmission time test was carried out based on global GPS clock synchronisation technology, test program is shown in Fig. 5.
detection and filtering algorithms. Station systems are unified by GPS, so the overall test system meets the testing needs for this time. At the same time, the Control Centre Station to Mu-Du master station; control; 2652 J. Eng.

Then, the whole group delay (the delay of DC bipolar blocking grid-load terminal; load-shedding process of wireless 4G private network entire group action time is 261 ms, with an average of 226.5 ms. The time accuracy of the selected high-precision time tester is 1 μs, and the time error with each control station system is within 1 ms. Among them, \( T_0 \), \( T_1 \), \( T_2 \), \( T_3 \) are the event time recorded by each control station system, and the GPS time is obtained through the time synchronisation device in the station, with the timescale accuracy of 1 ms; \( T_a, T_b \) are, respectively, self-aligning by the external GPS clock of the high precision time tester to obtain the switch null contact action time, with the timescale accuracy of 1 ms. The time accuracy of the selected high-precision time tester is 1 μs, and the time error with each control station system is within 1 ms.

After being tested, the average error of the test time tester participated in the test is < 70 μs. At the same time, all control station systems are unified by GPS, so the overall test system meet the testing needs for this time.

Selecting one dedicated optical fibre user, respectively, under the four precise load-shedding substations, and performing time test for each user’s branch switch auxiliary node. At the same time, selecting a wireless 4G user under Yushan substation for testing. User terminal action time test is shown in Table 3. The overall load-shedding process of wireless 4G private network entire group action time is 261 ms, the fastest action time of the whole group of fibre optic cable is 212 ms, with an average of 226.5 ms.

### 5 Frequency analysis based on zero-crossing detection and filtering algorithms

In Wu-Jang substation, DEWETRON data logger was used to measure and record the 500 kV busbar voltage waveform at DC-blocking time. The sampling frequency was 10 KHz. The voltage measurement data were drawn as shown in Fig. 6. During DC blocking, the voltage waveform in the voltage measurement window is distorted.

The voltage frequency value can be obtained from the voltage recorded value analysis. Traditional frequency measurement includes zero-crossing algorithm, discrete Fourier transform and recursive DFT algorithm. The zero-crossing algorithm tracks the voltage frequency by calculating the adjacent zero-crossing time intervals. The recorder records a series of offline data sequences \((T_o, V_o), (T_1, V_1), \ldots, (T_{k-2}, V_{k-2}), \ldots\). By the zero-crossing detection calculation of the adjacent two voltage symbols of different data points, the zero-crossing time was obtained [10–12].

Linear zero-crossing time calculation formula,

\[
t = t_k - \frac{t_k - 1 - t_k}{V_k - V_{k-1}}
\]

In the formula, \( V_k, t_k \) are the \( k \)-th sample of voltage data and sampling time; \( t \) is the zero-crossing point of calculation. Through the zero-crossing algorithm to measure the voltage waveform of the frequency tracking analysis, the frequency waveform shown in Fig. 7 is obtained. The lowest frequency occurs in the period of waveform distortion, the lowest frequency is 49.528 Hz, judging the data of this point is the frequency measurement error caused by voltage distortion. If we consider the influence of voltage distortion to the zero-crossing algorithm, the lowest frequency is 49.988 Hz. The steady-state system frequency is 50.03 Hz and the frequency decrease is 0.042 Hz.

From the above test results, it can be seen that the voltage of the system will be subjected to 1 to 2 cycles of distortion when the Jin-Su DC-blocking occurred. The distortion of this voltage will affect the common frequency tracking algorithm and cause the oscillation of the frequency waveform, making the frequency a large drop within a distortion wave scope. In order to reduce the influence of voltage distortion on the frequency measurement, the voltage waveform is filtered by the filtering algorithm first, and then the voltage frequency is tracked using the zero-crossing algorithm. Then, the waveform shown in Fig. 8 can be obtained [13–15].

![Image](image-url)

**Fig. 5** Precision load control time test of ‘Source-Grid-Load’ system

**Table 3** Time test of users’ terminal command action

<table>
<thead>
<tr>
<th>User type</th>
<th>Time scale of DC power loss</th>
<th>Time scale user-side switch auxiliary node action</th>
<th>The whole group action time, ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>fiber user 1</td>
<td>14:04:57:530</td>
<td>14:4:57:768</td>
<td>238</td>
</tr>
<tr>
<td>fiber user 2</td>
<td>14:4:57:759</td>
<td></td>
<td>229</td>
</tr>
<tr>
<td>fiber user 3</td>
<td>14:4:57:742</td>
<td></td>
<td>212</td>
</tr>
<tr>
<td>fiber user 4</td>
<td>14:4:57:757</td>
<td></td>
<td>227</td>
</tr>
<tr>
<td>wireless 4G user</td>
<td>14:4:57:791</td>
<td></td>
<td>261</td>
</tr>
</tbody>
</table>

![Image](image-url)

**Fig. 6** Busbar voltage curve of Wujiang substation when ‘9.19’ Jin-Su DC blocking fault
can be seen from the simulation results that the frequency tracking after filtering can reduce the influence of voltage distortion on the frequency measurement but cannot be completely eliminated.

The whole-grid frequency drops to 49.97 Hz after blocking fault, and the bus voltage frequency of 500 kV Wu-Jiang substation (about 1.8 km away from UHV Su-Zhou converter station) is illustrated in Fig. 8. Among them, at the moment of DC blocking, since the large group of reactive power compensation filters in the converter station fails to be cut-off in time, the bus voltage of Wu-Jiang station instantaneous rise and the voltage waveform is slightly distorted, resulting in transient moment of the data window of the frequency measurement algorithm and making a moment measurement frequency error. The actual frequency of the actual power grid should ignore the transient measurement error of the first three cycles when the DC-blocking fault occurs.

6 Conclusion
This paper focuses on real load-shedding verification of large-scale source-grid-load friendly interactive system, introducing an effective strategy validation technique based on preset instruction release mode, a time test method of real load-shedding control command transmission and system dynamic frequency calculation, which provide technical means and effective analysis for system commissioning test method. The action time of wireless 4G private network group is 261 ms, and the fastest whole action time of group of fibre optic cable is 212 ms, with an average of 226.5 ms, meeting the time requirement of quick system load shedding protection. Frequency analysis of different algorithms is carried out around bus voltage recording data, which realised the accurate measurement and calculation of grid frequency at the time of real load-shedding verification fault and verified the frequency control effect of source-grid-load system on emergency response to large grid faults.

7 Acknowledgments
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8 References