Improvement of primary frequency modulation test method of renewable energy stations in North-west Power Grid

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Abstract. In recent development of renewable energy power generation, the operation and structure of the power grid are becoming more and more complex, the difficulty of power balance and frequency regulation is increasing. North-west Power Grid took the lead in carrying out renewable energy frequency modulation function transformation and performance test technology research in 2016, and developed a primary frequency modulation function test method for renewable energy stations in the North-west transmission-end large power grid. In this paper, by calculating and analyzing the response data of some renewable energy stations when Yindong HVDC is blocked, combined with the fast frequency response test results of a renewable energy station, this paper analyzes the shortcomings of the current fast frequency response function test methods of the renewable energy stations of the North-west Power Grid, and put forward suggestions for improvement to provide technical support for the promotion of the primary frequency modulation function of renewable energy stations in the northwest transmission power grid.

1. Introduction

In recent years, renewable energy power generation represented by wind power and photovoltaics has developed rapidly. As the proportion of wind power and photovoltaic power in the grid continues to increase, UHV DC transmission is gradually put into operation, the operation and structure of the grid are becoming more and complex, and the power balance and frequency regulation of the power system are becoming more difficult [1-2].

On the one hand, in order to promote the consumption of renewable energy in the grid, the conventional power supply of the North-west Power Grid has been turned on according to the “negative standby” arrangement, squeezing the space of conventional water and thermal power units with rotational inertia, and the power structure has undergone major changes. The available fast response resources of the power grid have gradually decreased. For the large transmission-end power grid such as the North-west Power Grid, the structural dilemma of the power grid frequency control characteristics has become increasingly obvious, and the risk of grid frequency security problems has further increased.

On the other hand, as of the end of 2019, the North-west Power Grid has built 9 UHV DC transmission channels. With the large-scale commissioning of UHV DC transmission projects, the high-power DC blocking problem caused by UHV DC transmission will pose a more serious threat to grid frequency security. There is an urgent need for renewable energy generating units to participate in
the primary frequency adjustment of the power grid to improve the safety level of the large power grid frequency at the sending end [3-4].

North-west Power Grid took the lead in carrying out renewable energy frequency modulation function transformation and performance test technology research in 2016. As of the end of 2019, the first batch of renewable energy stations in North-west Power Grid has basically completed functional transformation. The renewable energy in the network initially has the ability to adjust the frequency [5-7].

In order to verify the fast frequency response function of renewable energy stations, the North-west Power Grid developed a test method for the fast frequency response function of renewable energy stations in the North-west transmission-end large power grid. At present, this method has been widely used in the network. However, in the actual application process, through the analysis of the primary frequency modulation test results of the renewable energy stations and the analysis of the action of the renewable energy station when the power grid fails, it is found that this method still has some shortcomings. In this paper, by calculating and analyzing the response data of some renewable energy stations when Yindong HVDC is blocked, combined with the fast frequency response performance test results of a renewable energy station, this paper analyzes the shortcomings of the current fast frequency response function test methods of the renewable energy stations of the North-west Power Grid, and put forward suggestions for improvement to provide technical support for the promotion of the primary frequency modulation function of renewable energy stations in the North-west transmission power grid.

2. Improvement of renewable energy fast frequency response function test method in North-west power grid

After the renewable energy station completes the transformation of the fast frequency response function, it needs to be tested for functional verification. In January 2019, the North-west Regulation [2018] No. 225 issued by the North-west Branch of the State Grid Corporation of China clearly stipulated the test content of the primary frequency modulation of renewable energy stations. This is also the first time in China to pass the field feasibility verification of the fast frequency response function test method of the renewable energy stations [8-9].

The test content of the fast frequency response function of the renewable energy plant includes four items [10]:

(1) Frequency step disturbance test
(2) Simulated actual grid frequency disturbance test
(3) Anti-disturbance performance verification
(4) AGC coordination test

The purpose and focus of the four test contents are different. Among them, the simulated actual power grid frequency disturbance test can truly reflect the active power support capacity and response speed of the renewable energy plant when the power grid fails. The simulated actual power grid frequency disturbance curve adopted by the North-west Power Grid is shown in Figure 1 and Figure 2.

Figure 1. North-west Power Grid's simulated actual frequency up-disturbance curve.  
Figure 2. North-west Power Grid's simulated actual frequency down-disturbance curve.
There are three test indicators in the simulated actual power grid frequency disturbance test.

1) Qualified rate of fast frequency response output response
This index is mainly used to judge whether the maximum output of the fast frequency response of the renewable energy station can meet the frequency regulation requirements of the grid during the grid failure.

2) Qualified rate of fast frequency response integral power
This index is mainly used to judge whether the actual contribution of the fast frequency response of the renewable energy station can meet the actual demand of the grid frequency adjustment during the grid failure.

3) Qualified rate of fast frequency response
This index is the only basis for this test. North-west Power Grid requires that the qualified rate of fast frequency response should not be less than 60%.

The current test method for simulating actual grid frequency disturbances gradually reveals shortcomings and shortcomings in the actual frequency modulation response of renewable energy stations during grid failures and the actual application of the primary frequency modulation function promotion of renewable energy stations.

On June 19, 2019, a total of 17 renewable energy stations were put into primary frequency modulation during the lock-up period of Yindong HVDC. Although some stations met the requirements of the North-west Power Grid during this primary frequency modulation process, their regulation performance was not ideal.

The actual movement data of 2 renewable energy plants are selected for analysis. The active power of station 1 before the failure was 7.26MW, the output reached 14.7% of the rated power, and the fast frequency response when the grid frequency reached 50.1Hz. As shown in Figure 3.

![Figure 3. Fast frequency response curve of station 1.](image)

The active power of station 2 before the failure was 8.76MW, the output reached 43.8% of the rated power, the fast frequency response, when the grid frequency reached 50.06Hz. As shown in Figure 4.

![Figure 4. Fast frequency response curve of station 2.](image)
The station data during the fault period are analyzed and calculated, and the results are shown in Table 1.

| Station name | Station type | Installed capacity (MW) | Qualified rate of output response (%) | Qualified rate of integral electric quantity (%) | Fast frequency response pass rate (%) |
|--------------|--------------|-------------------------|--------------------------------------|-----------------------------------------------|--------------------------------------|
| Station 1    | Wind farm    | 49.5                    | 52.73                                | 73.88                                         | 63.30                                |
| Station 2    | Photovoltaic power station | 20                      | 57.27                                | 70.54                                         | 63.91                                |

It can be concluded from Table 1 during the Yindong HVDC blocking period of station 1, the qualified rate of output response is 52.73%, the qualified rate of integral electricity is 73.88%, and the qualified rate of fast frequency response is 63.30%. And as for station 2 during the Yindong HVDC blocking period, the qualified rate of output response is 57.27%, the qualified rate of integrated electricity is 70.54%, and the qualified rate of fast frequency response is 63.91%. All meet the current requirements for simulating actual grid frequency disturbance testing. But judging from the actual response waveform, there is an overshoot phenomenon in station 1 after the frequency is restored, and the overshoot is far greater than the theoretical value of power regulation. Moreover, the output response qualification rates of station 1 and station 2 are both low, and compensation cannot be carried out to the greatest extent when the frequency value fluctuates the most.

During the primary frequency modulation performance test of renewable energy stations, it was also found that some stations had problems with excessive power regulation. Take the simulated actual grid frequency disturbance test data of station 3 as an example. The up-disturbance test waveform and the down-disturbance test waveform of station 3 simulated actual grid frequency are shown in Figure 5 and Figure 6 respectively.

![Figure 5](image1.png)  ![Figure 6](image2.png)

*Figure 5. Simulated the actual power grid frequency up-disturbance test curve of station 3.*  *Figure 6. Simulated the actual power grid frequency down-disturbance test curve of station 3.*

Analyze and calculate the test data, and the results are shown in Table 2.

| Station name | The test conditions | The disturbance type | Qualified rate of output response (%) | Qualified rate of integral electric quantity (%) | Fast frequency response pass rate (%) |
|--------------|---------------------|----------------------|--------------------------------------|-----------------------------------------------|--------------------------------------|
| Station 3    | Condition 3         | Up-disturbance       | 89.34                                | 193.64                                         | 141.49                                |
|              | Condition 1         | Down-disturbance     | 107.22                               | 58.11                                          | 82.67                                 |
According to the results in Table 2, it can be concluded that the output response qualification rate of station 3 is 189.23%, the integral power qualification rate is 91.87%, and the fast frequency response qualification rate is 140.55% when performing the up-disturbance test under working condition 3. When the station 3 performs the down-disturbance test under working condition 1, the qualified rate of output response is 227.94%, the qualified rate of integrated electricity is 102.16%, and the qualified rate of fast frequency response is 165.05%. Judging from the test waveform, the overshoot of active power output is obvious, the overshoot basically reaches about twice the theoretical value, and the integral power is reasonable in terms of the entire frequency disturbance period. But if you look at it in sections, there is a negative compensation phenomenon in some periods.

For the above situation, this paper improves the test method of simulating actual power grid frequency disturbance, and proposes a new method for judging test results. In order to fully ensure that during the actual change of the grid frequency, the active power output and integrated electricity of the renewable energy plant can meet the needs of grid regulation in real time during the entire adjustment process, and the fast frequency response qualification rate is no longer used as the judgement basis. The evaluation should be done in a way that both accordance with the output response qualified rate and the integrated power qualified rate results, and the results of the simulation of the actual grid frequency disturbance test should be judged in sections.

For the typical simulation actual power grid frequency test curve developed by North-west Power Grid, it can be segmented according to the frequency change trend. The part with a larger change trend is the first segment, and the part with a gentle change trend is the second segment. In addition, the selection of the first stage should take into account the response lag time of 2s. For the judgment of the two stages of test results, different judgment requirements should be adopted. Taking into account the actual situation of response lag, the requirements for the first stage can be appropriately relaxed, and the requirements for the second stage can be relatively strict. The specific requirements are shown in Table 3.

| The disturbance type | Data segment                  | Data period (s) | Qualified rate of output response (%) | Qualified rate of integral electric quantity (%) |
|----------------------|-------------------------------|-----------------|---------------------------------------|-----------------------------------------------|
| Up-disturbance       | The first paragraph           | 0-10            | 80-120.                               | 80-120.                                       |
|                      | The second paragraph          | 10-50           | 90-120.                               | 90-120.                                       |
| Down-disturbance     | The first paragraph           | 0-10            | 80-120.                               | 80-120.                                       |
|                      | The second paragraph          | 10-50           | 90-120.                               | 90-120.                                       |

Figure 7. Simulated the actual power grid frequency up-disturbance test curve of station 4.

Figure 8. Simulated the actual power grid frequency down-disturbance test curve of station 4.
In order to verify the above method, the test data of station 4 is introduced. The up-disturbance test waveform and down-disturbance test waveform of the simulated actual grid frequency of station 4 are shown in Figure 7 and Figure 8.

Perform statistical analysis on the test data of station 3 and station 4 according to the above method. The 8s after the frequency crosses the dead zone plus the response lag time of 2s, a total of 10s test data is selected for the first segment. And 50s after test data is selected for the second segment. The final analysis results are shown in Table 4.

| Station name | The disturbance type | Data segment | Qualified rate of output response (%) | Qualified rate of integral electric quantity (%) | Determine the results |
|--------------|----------------------|--------------|-------------------------------------|-----------------------------------------------|----------------------|
| Station 3    | Up-disturbance       | The first paragraph | 89.34                             | 114.57                                       | Pass                 |
|              |                      | The second paragraph | 538.63                           | 416.99                                       | Not pass             |
|              | Down-disturbance     | The first paragraph | 107.22                            | 82.22                                        | Pass                 |
|              |                      | The second paragraph | 120.23                           | 52.61                                        | Not pass             |
| Station 4    | Up-disturbance       | The first paragraph | 91.08                             | 87.58                                        | Pass                 |
|              |                      | The second paragraph | 102.56                           | 117.57                                       | Pass                 |
|              | Down-disturbance     | The first paragraph | 92.69                             | 81.60                                        | Pass                 |
|              |                      | The second paragraph | 93.04                             | 92.83                                        | Pass                 |

3. Conclusions
It can be seen from the judgment result that the current method of judging that the qualified rate of fast frequency response reaches 60% is still flawed to a certain extent. The segmented judgment method proposed in this paper by simulating actual grid frequency disturbance test results can more accurately and comprehensively reflect the actual situation of primary frequency modulation of renewable energy stations. After accurate verification of this determination method through a large number of new energy stations primary frequency modulation test data, it can be fully applied to the grid detection work of the primary frequency modulation function of new energy stations of North-west Power Grid.

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