The Development and Analysis of Primary Frequency Regulation and AGC Test in Shandong Power Grid

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Abstract. Based on the 2018 entire-grid primary frequency regulation and AGC test, the concrete procedures and obtained results of Shandong power grid are analyzed at length. In combination with the published standards and specifications, the new techniques adopted in the test are analyzed. And then, according to the emerging problems during the test, the improvement measures and optimization suggestions are proposed. With the help of analyzed results and proposed advices, the further technical supervision work of source-network coordination can be developed and thermal unit performance can be improved.

1. Introduction

The power and frequency regulation is one of the most important missions of power system operation [1]. The primary power regulation is carried out through the primary frequency regulation (PFR) [2]-[4], and the secondary power regulation is carried out through the automatic generation control (AGC) [5]-[7]. Further, the PFR and AGC take on the power and frequency regulation mission at the time scale of seconds to minutes, which are important to the power system power balance and frequency stability [8], [9]. In the meantime, the renewable generations have undertaken a rapid development [11], [12]. Since the renewable generations, such as the wind turbine generators (WTGs) and photovoltaic (PV) modules, are usually intermittent, random and uncontrollable, the power and frequency regulation duties of thermal units are aggravated [12]-[14]. So, the entire-grid AGC and PFR test play a significant role in the power system operation and frequency security.

The influence of fast PFR and synthetic inertia on power system power and frequency control has been analyzed in detail [15]. And the performance of frequency control devices with different frequency deviation signal estimation methods have been compared [16]. The models of Turbine and corresponding governor system have been established, and the PFR performance has been assessed and optimized [17]. In order to assess the operation performance of Li-ion battery storage system providing PFR, field tests have been carried out, in which the capacity measurements, hybrid pulse power characterization measurements
and AC impedance measurements are carried out [18]. Moreover, an AGC model has been established using the deviation settlement mechanism and the corresponding performance has been estimated [19]. The AGC performance indicators have been proposed, considering the dynamic process of thermal units tracking load instructions [20]. Then, the AGC testing diagnostic analytic system has been developed [21], and the influence of PID controller on AGC performance has been analyzed [22].

In this paper, the concrete procedures and obtained results of Shandong power grid are analyzed at length, according to the 2018 entire-grid PFR and AGC test. And the new techniques adopted in the test are analyzed, in combination with the published standards and specifications. Moreover, the emerging problems of the entire-grid test are analyzed, and the corresponding improvement measures and optimization suggestions are proposed. The further technical supervision work of source-network coordination can be developed and thermal unit performance can be improved, based on the obtained results and proposed suggestions.

The rest of the paper is organized as follows. The Section II introduces the grid-related performance test in Shandong power grid. The standards, specifications and requirements of the entire-grid test are described in Section III. Moreover, the testing results and problems are analyzed in Section IV. Finally, the conclusion is drawn in Section V.

2. Grid-related Performance Test in Shandong Power Grid
The renewable energy integration and power receiving rate of Shandong power grid have been increasing greatly. And according to the data of Shandong development and reform commission, the installed capacity of renewable energy has arrived at 23.2944 million kWh and 18.55%. In more detail, the WTGs installed capacity has arrived at 10.6114 million kWh and is the fifth-highest in the nation. The PV installed capacity has arrived at 1052.31 million kWh and is the first-highest in the nation. Moreover, the seven items of the “five-AC and five-DC” high voltage (HV) engineering projects of the state grid electric power company are undertaken by the Shandong power grid. And the four items of eight ultra-HV (UHV) transmission channels planned in the national air pollution prevention and control action are managed and built by the Shandong power grid. The power receiving rate and renewable energy penetration of Shandong power grid would be surpass 30% and 20% respectively. So, the patterns and structures of power grid and sources would be changed by the establishment of high voltage engineering projects and the rapid development of renewable energy in the future two years.

With the development of large-capacity HV direct current (HVDC) projects, the frequency security and stability of Shandong power grid is facing rigorous challenges posed by the HVDC blocking. And the heat supply reformation of thermal power plants has been carried out, which improves the operation economy of cogeneration but decreases the spinning reserve and the frequency regulation capability. Further, the equivalent moment of inertia and the frequency and voltage regulation capability of Shandong power grid have been decreased. As the main units participating in the peak load shift and frequency regulation, the performance of thermal units are playing a more and more significant role. And the new trends pose challenges to the frequency regulation flexibility and peak load shift depth of thermal units.

In order to alleviate the aforementioned severe situations, the entire-grid PFR and AGC tests are carried out in Shandong power grid. The entire-grid thermal units have been examined through the PFR small-disturbance test from 2014. The thermal units after heavy repairs need to pass the PFR and AGC tests. And at least 20 units have passed the grid-related test up to the end of 2018. In addition, the remote PFR major-disturbance test are also carried out and more than 100 thermal units have passed the test, which realizes the remote supervision and control of entire-grid frequency regulation performance.
3. Test Requirement
The grid-related test of Shandong power grid is carried out seriously according to the national standard, occupation standard and company standard. Although these above three standards provide definite requirement on the PFR and AGC tests, there are a great deal of difference about the technical indicators, test methods and working condition selection. In order to eliminate differences and provide a unified testing standard, the state grid Shandong electric power research institute organized experts to develop and synthesize new standards and criterions, according to the various national standards and occupation standards, and the corresponding technical regulations of state grid electric power company and state grid Shandong electric power company. The two most important revisions of the testing standard are the maximum load increase magnitude requirement and the communication error of grid dispatch and thermal unit requirement.

3.1. Maximum Load Increase Magnitude Requirement
The main-steam pressure, main steam temperature, and fuel quantity of the thermal unit are set to the upper limit and the jaw opening of the turbine may already be nearing the upper limit, when the unit operates at the rated point. If the PFR occurs in this time, the jaw opening will increase, but the steam flow is restricted by the main-steam pressure, so the output increase is unapparent.

According to the test of thermal units, the output of normal units cannot arrive at 106% and there is no optimization strategy to improve the unit output to the above value. However, the unit output can arrive at 105%, so in the new developed PFR standard, the maximum load increase magnitude is set to 105%.

3.2. Communication Error Requirement
The basis and precondition of AGC is the communication signal accuracy. In the new revised testing standard, the measure errors of remote terminal unit (RTU) and distributed control system (DCS) should be limited at the range of -2%~+2%. And the errors of the provincial dispatching center control command and the DCS target value is ought to be limited at the range of -2%~+2%. As for the data checking of the unit and dispatching center, at least 5 data point should be taken into account and be even distributed between the stable load and rated load, which can assure that the communication accuracy of bi-directional signals.

4. Test Results and Problems Analysis
The 2018 Shandong power grid PFR and AGC tests are taken as examples, and the obtained results and problems are analyzed.

4.1. Thermal Unit Operation Mode
In the 2018 Shandong power grid entire-grid tests, the majority of thermal units after heavy repair operate at the single valve mode. And according to the regulations of unit manufacturers, the repaired thermal units should operate at the single mode for 1 month, so the PFR test only has the single valve mode, which cannot meet the national standard. In order to solve the problem, the single valve test can be carried out as soon as the completion of heavy repair and the test report can be made and updated to the dispatching management system (DMS). Then, after 1 month, the sequence valve test will be carried out and the report will be made and updated to the DMS when unit operation mode can switch into sequence valve mode.

4.2. PFR Intelligent Control Devices and Technique
Instead of traditional DCS control devices, a number of thermal units in Shandong power grid have been deployed with the NX-PFR intelligent control devices. As for the NX-PFR device, the embedded system and the high-frequency and high-precision sensor are utilized, which realize the high-speed and high-
precision collection of frequency signal. The frequency signal collection precision can arrive at 0.001 Hz and overcome the drawback of DCS that the signal inaccuracy would decrease the PFR qualification rate.

The interface of NX-PFR intelligent control devices is shown as Fig. 1. The advanced control strategy is based on active power dynamic changes and the control logic is integrated inside the device. According to the frequency deviation, the device generates different action amplitudes, which can assure that the qualification rate can meet requirements and decrease the PFR action numbers.

![Fig. 1 Intelligent control device interface.](image)

The comparison of PFR action numbers with and without the NX-PFR intelligent control device is shown in Fig. 2. It is obvious that the NX-PFR intelligent control device is able to decrease the action numbers of PFR and improve the signal precision. The qualification rate of PFR with the NX-PFR intelligent control device can arrive at 95.63%.

![Fig. 2 Comparison of PFR action numbers with and without the NX-PFR intelligent control device.](image)

4.3. PFR Overshoot

The thermal unit PFR test results are shown in Fig. 3. The test unit is a 350 MW subcritical unit and the operation condition is sequence valve mode and 75% load point. The initial load is 263.13 MW and the test value is -14 r/min. As the PFR command decrease, the unit can take action swiftly.
4.4 PFR Test Numbers

The +6 r/min PFR test process of a 330 MW subcritical unit is shown in Fig. 4. The PFR command is -11.43 MW and the maximum actual power decrease is 6042 MW, from 201.29 MW to 140.87 MW, and the water level fluctuation is drastic, from -172.64 mm to +68.74 mm, which impact the unit security operation greatly.

In the aforementioned test process, the repeating ±6 r/min and ±14 r/min tests are needed. Taking the 330 MW subcritical unit +14 r/min as an example, the step value of command is large and results in load overshoot, so the unit parameter and the boiler water level will fluctuate dramatically. And the corresponding unit protection may be closed and control parameters may be changed, in order to pass the PFR test, which influence the unit security operation. So the maximum PFR test numbers need to be restricted and the unit control and protection parameters and modes cannot be changed during the test process.
5. Conclusion
This paper analyzes the concrete procedures and obtained results of the 2018 Shandong power grid PFR and AGC test at length. The new adopted techniques and the emerging problems of the entire-grid test are also analyzed, and the corresponding improvement measures and optimization suggestions are proposed. The analysis results are useful to improve the unit grid-related performance and can be summarized as:

1. The valve flow rate curve should be adjusted to track the command signals and improve the action performance of PFR and AGC.
2. The thermal unit operation parameters should be adjusted to improve the ability of peak load shift and frequency regulation.
3. The single valve test can be carried out as soon as the completion of heavy repair and the test report can be made and updated to the dispatching management system (DMS). Then, the sequence valve test will be carried out and the report will be made and updated to the DMS after 1 month.
4. The NX-PFR intelligent control devices and the advanced control strategies are necessitated to improve the thermal active power and frequency control performance.
5. The examination of the minimum speed governing droop rate (4%~5%) needs to be taken to restrict the additional compensation value. Moreover, he maximum PFR test numbers need to be restricted and the unit control and protection parameters and modes cannot be changed during the unit grid-related test process.

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