Research on Static Var Generator Detection Method for New Energy Fields and Stations in Hunan Area

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Abstract. With the strategy of constructing new power system with new energy as the main body put forward, the installed capacity of new energy in Hunan area will usher in explosive growth during the 14th five-year Plan period. The safe and stable operation of new energy stations to power grid will also be increasingly intensified. The paper briefly introduces the working principle, working mode and application of SVG(Static Var Generator) device supporting new energy stations. Based on relevant standards, a test scheme suitable for new energy stations in Hunan province is proposed. Taking the SVG device supporting a new energy station in Hunan province as an example, the grid-connection performance test is carried out to comprehensively and scientifically evaluate the network-related performance of SVG devices in the new energy station.

Keywords. Static Var Generator, Reactive power compensation, New energy station, Grid connection performance test

1. Introduction
In recent years, the capacity of domestic new energy stations has increased substantially. Up to now, the installed capacity of new energy in Hunan province is close to 10 million kilowatts, accounting for nearly 20% of the total installed capacity of all kinds of power sources. It is expected that by the end of the "14th five-year Plan", the installed capacity of new energy in Hunan province will reach 25 million. With the large-scale increase of new energy stations, their influence on the power grid is also constantly strengthened. The performance of SVG devices equipped with each station will affect the safe and stable operation of the power grid. In view of the situation, Central China Power Grid has formulated implementation Rules for Grid-Connected Operation Management of Power Plants in Central China, which directly includes the performance and operation rate of SVG devices into the assessment scope. At the same time, the power grid also puts forward requirements on the power factor of some new energy sites. When the sites do not generate power, SVG devices need to be invested to compensate the reactive power of the combined sites and improve the power factor of the sites. Therefore, in order to improve the netd-related performance of the new energy sites, it is necessary to conduct performance tests on the SVG devices equipped with each site. At first, the paper introduces the SVG device's working principle, working mode and the operations of the new energy usage scenarios, secondly introduces test related technical standards, and put forward the corresponding test plan according to these standards, and finally a new energy in hunan area operations for grid performance tests, the comprehensive assessment scientifically the main performance of the new energy depot supporting SVG device.
2. Introduction to Static Var Generator

The main topology of Static Var Generator is a three-phase bridge inverter. By controlling the output voltage of the AC side or adjusting the output current of the AC side, the device can output advanced reactive power or lagging reactive power [1-3]. Compared with traditional reactive power compensation devices, SVG has the advantages of small volume, low loss, large adjustable range, fast response speed and low harmonic content [4-6]. At present, SVG devices are widely used in new energy stations to compensate the reactive power of parallel nodes. The main circuit of SVG device can be divided into voltage type and current type, and voltage type bridge inverter circuit is basically adopted in the market [7-8]. Most SVG devices supporting new energy stations in Hunan are directly connected to 35kV busbars, and a few are connected to 35kV busbars through 10kV/35kV boost transformers. The working mode of SVG device can be generally divided into constant device reactive power control mode, constant system reactive power control mode, constant power factor control mode and constant voltage control mode [9-10]. Although the name of the mode on SVG devices of various manufacturers is slightly different, their actual functions are almost the same. Some SVG devices of some manufacturers have also developed the functions of harmonic elimination and flicker suppression [11-12].

3. New Energy Station Matching SVG Device Detection Method

The reactive power supply of the new energy station mainly includes fan converter, SVG and FC filter. When the new energy station loses its energy source, only SVG can provide advanced reactive power for the power grid to reduce the voltage of the power grid. The new energy station basically adjusts the system voltage through the AVC (Automatic Voltage Control) system. After the SVG device is connected to the AVC system in the remote mode, it generally works in the constant device reactive power mode and executes the reactive power instruction assigned by the AVC system [13-14]. The performance of SVG in constant device mode affects the performance of AVC system in regulating power grid voltage. Therefore, it is necessary to carry out performance test in SVG in constant device reactive mode. The purpose of this test is to improve the voltage regulation performance of the new energy station, so the test focus is mainly on the performance of SVG device in constant device reactive power control mode and constant voltage mode.

The test method is mainly carried out according to the industrial standard DL/T 1215.1-2013 "Chain Static Synchronous Compensator Part 1: Functional Specification Guide" and the enterprise standard Q/GDW 1244.4-2014 "Chain Static Synchronous Compensator Part 4: Field Test" of State Grid Corporation of China. The test items mainly include: Continuous operating range, voltage characteristics, dynamic characteristics and load characteristics.

3.1. Continuous Operating Range

The continuous running range test of SVG device is used to verify the maximum capacitive reactive power output and the maximum inductive reactive power output that SVG device can work under continuous running mode. Control mode is divided into constant device reactive power control mode and constant system voltage control mode.

3.1.1. Constant Device Reactive Power Control Mode. Test the reactive power generation capability of SVG device in constant device reactive power control mode. Set SVG device as constant device reactive power control mode, adjust the output reactive power Qref of SVG device, so that the output reactive power of SVG device varies from rated inductive reactive power to rated capacitive reactive power. The general set values are 0, 0.5Qn, Qn, 0.5Qn, 0, -0.5Qn, -Qn, -0.5Qn, 0 (Qn is the rated reactive power of SVG device), and each set value should be kept for at least 5min. During the test, 110kV bus voltage and 35kV bus voltage should be monitored to prevent voltage beyond the normal operation range. Check and record whether the output voltage/current and dc capacity voltage of the SVG device are normal.
3.1.2. **Constant System Voltage Control Mode.** Test the reactive power generation capability and slope characteristics of SVG device under constant system voltage control mode. SVG device is set in constant system voltage control mode, and the target voltage value of SVG device is set to several values higher than the operating voltage of the system bus, so that the reactive power of SVG device increases gradually from 0 to rated capacitive reactive power. The target voltage value of SVG device is set to several values lower than the operating voltage of the system bus, so that the reactive power of SVG device increases gradually from 0 to the rated inductive reactive power. Each target voltage value should be maintained for at least 5min. During the test, 110kV bus voltage and 35kV bus voltage should be monitored to prevent the voltage from exceeding the normal operation range. Check and record whether the output voltage/current and dc capacity voltage of SVG device are normal.

3.2. **SVG Voltage Characteristics**
Test the voltage characteristics of SVG device in constant system voltage control mode. The SVG device is set as constant system voltage control mode, and the target voltage value $U_{\text{ref}}$ is changed to adjust the reactive power output of THE SVG device until the rated inductive and capacitive output is obtained. The 110kV bus voltage and 35kV bus voltage are monitored during the test to prevent the voltage from exceeding the normal operation range. Check and record whether the output voltage/current and dc capacity voltage of SVG device are normal.

3.3. **SVG Dynamic Features**
Test the dynamic characteristics of SVG device in constant system voltage control mode. The SVG device is set as constant system voltage control, and the step change method is adopted to change the target voltage value $U_{\text{ref}}$ of SVG device to make the inductive or capacitive reactive power output of SVG device produce step response. Meanwhile, the change waveform of inductive or capacitive reactive power and current output of SVG device is obtained by recording wave. To test whether the response time of SVG device meets the standard requirements.

3.4. **SVG Payload Features**
Test the load characteristics of SVG device in constant system voltage control mode. The SVG device is set as constant system voltage control, and the reactive power output characteristics of SVG device are tested by switching load or switching capacitance and reactance. The feature of an SVG device for reactive power compensation for load should be within the limits specified for its entire continuous operation.

4. **Typical Case Analysis of Grid Connection Performance Test for SVG Device in a New Energy Station in Hunan Province**
In the chapter, the grid connection performance test project of SVG device supporting a wind farm in Hunan Province is analyzed as a typical case. The rated compensation capacity of SVG device ranges from inductive 10Mvar to capacitive 10Mvar, and the voltage level is 35kV. The test instrument adopts dewe-5000 data acquisition device, and the main wiring diagram and measuring point position of wind farm are shown in figure 1.
4.1. Analysis of Continuous Running Range Detection Results

4.1.1. Constant Device Reactive Power Control Capability. SVG of wind farm dynamic reactive power compensation device operates in constant reactive power control mode. The reactive power output of SVG of wind farm dynamic reactive power compensation device is adjusted gradually from 0 to the rated capacitive reactive power value, and then gradually changes from the rated capacitive reactive power value to 0. Adjust the reactive power output of SVG from 0 to rated inductive reactive power, and then from rated inductive reactive power to 0. The curve of reactive power output by SVG of reactive power compensation device is shown in figure 2, and the measurement results are shown in table 1.

![Figure 2](image-url)  
**Figure 2.** Output reactive power of SVG system under constant reactive power control mode.
Table 1. Test results under constant reactive power control mode.

| Set reactive power value (Mvar) | Measured value of SVG output reactive power (Mvar) | Steady-state error (%) |
|---------------------------------|--------------------------------------------------|------------------------|
| 0                               | 0.08                                             | 0.80                   |
| 5                               | 5.01                                             | 0.10                   |
| 10                              | 10.02                                            | 0.20                   |
| 5                               | 5.08                                             | 0.80                   |
| -5                              | -5.02                                            | 0.20                   |
| -10                             | -10.02                                           | 0.20                   |
| -5                              | -5.07                                            | 0.70                   |

According to article 5.2.7 of the industrial standard DL/T 1215.1-2013 "Chained Static Synchronous Compensator -- Part 1: Functional Specification Guide", the maximum allowable deviation between the actual reactive power output of chained SVG (also known as STATCOM) and the set value in steady state is usually no more than ±2.5%. The test results show that the maximum deviation between the actual output reactive power of SVG and the set value is 0.80%, which meets the standard requirements.

4.1.2. Constant Voltage Control Capability. Wind farm dynamic reactive power compensation device (SVG) operates in constant voltage control mode. By setting the voltage target value in SVG background, the SVG reactive power output is changed and the voltage of wind farm parallel node is adjusted. The corresponding line voltage change curve is shown in figure 3, and the measurement and calculation results are shown in table 2.

Figure 3. Total reactive power output from 110 kV joint point voltage and SVG under constant voltage control mode.
Table 2. Test results under constant voltage control mode.

| Line voltage reference value (kV) | 110 kV connection point line voltage measurement value (kV) | Steady-state deviation (%) |
|-----------------------------------|-------------------------------------------------------------|----------------------------|
|                                   | A-B phase | B-C phase | C-A phase | A-B phase | B-C phase | C-A phase |
| 117                               | 117.05    | 116.57    | 116.81    | 0.04      | 0.37      | 0.16      |
| 118                               | 118.14    | 117.72    | 117.86    | 0.12      | 0.24      | 0.12      |
| 119                               | 119.09    | 118.60    | 118.79    | 0.08      | 0.34      | 0.18      |
| 118                               | 118.15    | 117.59    | 117.74    | 0.13      | 0.35      | 0.22      |
| 117                               | 117.18    | 116.61    | 116.71    | 0.15      | 0.33      | 0.25      |
| 116                               | 116.27    | 115.90    | 115.73    | 0.23      | 0.09      | 0.23      |
| 115                               | 115.21    | 114.72    | 114.68    | 0.18      | 0.24      | 0.28      |
| 116                               | 116.33    | 116.06    | 115.76    | 0.28      | 0.05      | 0.21      |
| 117                               | 117.32    | 117.37    | 116.91    | 0.27      | 0.32      | 0.08      |

4.2. Analysis of Voltage Characteristic Test Results
When SVG device of wind farm runs in constant voltage control mode, adjust the voltage target value of SVG device to gradually change the reactive power output from 0 to the rated capacitive reactive power value; Adjust the voltage target value of SVG device to gradually change the reactive power output from 0 to the rated inductive reactive power value. The test results are shown in table 3.

Table 3. Slope characteristic test.

| Capacitive test | Perceptual test |
|-----------------|-----------------|
| Output current of SVG device(A) | 1.01 | 80.81 | 160.37 |
| 35kV bus line voltage (kV) | 37.09 | 37.67 | 38.04 |
| Perceptual slope (%) | 2.81 |

Perceptual test

| Output current of SVG device(A) | 1.13 | 80.21 | 160.06 |
| 35kV bus line voltage (kV) | 36.75 | 36.21 | 35.67 |
| Capacitive slope (%) | 3.20 |

The actual test shows that the capacitive slope of SVG device is 2.81%, the perceptual slope is 3.20%, and the total slope is 3.01%.

4.3. Analysis of Dynamic Response Characteristics Test Results
The SVG device of wind power is set as constant voltage control mode, and the reactive power of SVG is controlled to change step within its rated range by raising or lowering the system voltage reference value in the background of SVG control system, so as to verify the dynamic step response capability of SVG. The measured results of SVG dynamic characteristics test are shown in table 4, and the corresponding curve of line voltage change and reactive power change is shown in figure 4 to figure 9.
Figure 4. The line voltage reference value changed from 117.8kV to 119.3kV step.

Figure 5. The line voltage reference value changed from 119.3kV to 117.8kV step.

Figure 6. The line voltage reference value changed from 117.8kV to 116.3kV step.

Figure 7. The line voltage reference value changed from 116.3kV to 117.8kV step.

Figure 8. The line voltage reference value changed from 116.3kV to 118.3kV step.

Figure 9. The line voltage reference value changed from 118.3kV to 116.3kV step.

Table 4. Test results of SVG dynamic response characteristics under constant voltage control mode.

| Line voltage reference value (kV) | Measured value SVG compensation capacity (Mvar) | Step response time (ms) |
|----------------------------------|-----------------------------------------------|------------------------|
| From 117.8 to 119.3              | From 2.04 to 8.05                             | 24                     |
| From 119.3 to 117.8              | From 8.45 to 2.36                             | 28                     |
| From 117.8 to 116.3              | From 1.84 to -3.92                            | 27                     |
According to the industrial standard DL/T 1215.1-2013 "Chain Static synchronous compensator -- Part 1: Functional Specification Guide", article 5.2.8 stipulates that step response time is generally 10ms ~ 50ms. The test results show that the maximum step response time of SVG device in wind farm is 28 ms, which meets the standard requirements.

4.4. Analysis of Load Characteristic Test Results
The SVG device of wind farm was set as constant voltage control mode, and the voltage reference value of this test was set as 117 kV. The dynamic response ability of SVG to maintain voltage stability of the system is verified by switching capacitor (FC). The measurement results of external disturbance response are shown in table 5, and the curve of line voltage change and reactive power change during the test is shown in figure 10 and figure 11.

![Figure 10](image1.png)
![Figure 11](image2.png)

**Table 5.** Measurement results of external disturbance response.

| FC output reactive power Step change (Mvar) | Measured value | Step response time (ms) |
|-------------------------------------------|----------------|------------------------|
| SVG Compensation Capacity (Mvar)          |                |                        |
| From 0 to 4.86                            | From 2.92 to -2.17 | 40                     |
| From 4.87 to 0                            | From -2.82 to 2.46  | 29                     |

5. Conclusion
The article main basis operations supporting the new energy of SVG device related standards and the relevant requirements after the grid put forward targeted test items and test methods, and live on SVG device was carried out for network performance testing, comprehensive fully assessed the operations supporting the new energy of SVG device for network performance, in order to ensure the SVG device can meet the requirements of power grid access. It ensures the safe and stable operation of the power system, and also accumulates typical experience for the continuous improvement of network related performance of the new energy station during the "14th Five-year Plan" in Hunan.
References

[1] Qi J, Zhao W and Bian X 2020 Comparative study of SVC and STATCOM reactive Power compensation for prosumer microgrids with DFIG-based wind farm integration IEEE Access (99): 1-1.

[2] Ernst S, Kotulski L and Lerch T 2021 Application of reactive power compensation algorithm for large-scale street lighting Journal of Computational Science 51(2): 101338.

[3] Ernst S, Kotulski L and Lerch T 2021 Application of reactive power compensation algorithm for large-scale street lighting Journal of Computational Science 51(2):101338.

[4] Xu H, Chen H and Zhang J H 2020 Application prospect of new dynamic reactive power compensation in hunan power grid Hunan Electric Power 40(1): 4.

[5] Tripathy M, Samal R K 2019 A new perspective on wind integrated optimal power flow considering turbine characteristics, wind correlation and generator reactive limits Electric Power Systems Research 170(5): 101-115.

[6] Liao T F 2019 Hybrid modulation strategy for reactive compensation of PV grid-connected inverter Intelligent Automation and Soft Computing 25(4): 695-704.

[7] Lei Y, Li T and Tang Q 2020 Comparison of UPFC, SVC and STATCOM in improving commutation failure immunity of LCC-HVDC systems IEEE Access (99): 1-1.

[8] Ma C M, Xie D and Yu Z W 2013 Voltage control strategy of SVG Electric Power Automation Equipment 33(03): 96-99+107.

[9] Zhu X L, Zhang Y and Gao K 2009 Research on the compensation of reactive power for wind farms Power System Protection and Control 37(16): 68-72.

[10] Peng Y Li Y and Lee K Y 2020 Coordinated control strategy of PMSG and cascaded h-bridge STATCOM in dispersed wind farm for suppressing unbalanced grid voltage IEEE Transactions on Sustainable Energy (99): 1-1.

[11] Yang L and Peng Z 2017 A hybrid static compensator for dynamic reactive power compensation and harmonic suppression Journal of power electronics: A publications of the Korean Institute of Power Electronics 17(3): 798-810.

[12] Kashif M, Hossain M J and Zhuo F 2018 Design and implementation of a three-level active power filter for harmonic and reactive power compensation Electric Power Systems Research 165(12): 144-156.

[13] Li Y, Feng Y and Zhang H 2018 An adaptive zone-division approach for voltage control of power grid with distributed wind farms: A case study of a regional power grid in central south China International Journal of Electrical Power & Energy Systems 103(12): 652-659.

[14] Yang L, Zhou Z R and Guo C 2020 Study on voltage stability control strategy of power grid with SVG coordinated wind farm Advanced Technology of Electrical Engineering and Energy 39(10): 55-64.