

Research and Application of Low Voltage Ride Through Testing Device for Low Voltage Frequency Converter in Thermal Power Plant

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Abstract: In order to improve the Low Voltage Ride through (LVRT) level of the low voltage auxiliary frequency converter in the thermal power plant and effectively solve problems including the inaccurate drop time of voltage drop device, which is controlled by the switching structure of the traditional multi-winding transformer, excessive magnetizing inrush current occurs during the closing process, and the 30KW testing device for LVRT of the frequency converter in the thermal power plant is developed. It is designed with a three-phase four-wire back-to-back power electronic topology, together with adaptive fuzzy PI control algorithm. They can precisely set the voltage drop amplitude and time, ensuring automatic periodic cycle test controlled by upper computer. A LVRT field experiment has been carried out on low-voltage auxiliary frequency converter both before and after the transformation in a thermal power plant in Jiangxi Province. It proves that the dynamic response time of the power electronic voltage drop device is less than 5ms, the harmonic content in the converter voltage output is less than 0.5%. Additionally, the device boasts convenient operation and well-developed protection mechanism.

1. Introduction

At present, the frequency converters are widely used in the auxiliary units of the thermal power unit, which have great advantages in realizing the stepless speed regulation of the motor, the soft start of the auxiliary machine, and the economic operation[1-2]. The LVRT capability of the low voltage auxiliary machine of the thermal power unit is far from satisfaction, and most of them lack the ability of LVRT[3]. In January 2011, the damage of the outdoor transformer of a thermal power plant caused the grounding fault of the 500kV system of the power grid and made the power supply of the coal feeder trip, causing the shutdown of one 600MW unit of the running plant and the other one of a neighboring power plant, posing a huge threat to the safe operation of the power grid. In a petrochemical company's thermal power plant, due to the power plant power failure in switching or the emergence of interference electricity, the boiler, with frequency converting control, was completely stopped, causing the boiler to be shut down, resulting in huge losses to the production of the unit and the chemical plant installations[4-6].

North China Electric Power University, CSIC 718, Gansu Electric Power Research Institute and other colleges and universities have carried out comparative analysis of various reforming schemes for
LVRT of auxiliary machine converters in thermal power plants. However, no research has been done on the testing device for LVRT of the converters in thermal power plants. [7-9]

At present, the voltage drop device of the converter with secondary side multi-winding structure is bulky and heavy, and can even cause potential threat to the running equipment especially when inrush current occurs due to the switching of the device caused by the mismatch of the difference of the upper and lower switch steps. The Electric Power Research Institute of State Grid Jiangxi Electric Power Company has developed a testing device for the LVRT of the auxiliary machine converter in thermal power plants based on the accumulation of the development and study of power electronics technology for many years. It adopts the adaptive fuzzy PI control strategy to overcome the problem that the traditional PI controller cannot guarantee the voltage amplitude to have steady state accuracy and dynamic performance. The device topology creatively adopts the back-to-back three-phase four-wire bridge arm structure, and the output voltage can realize both three-phase voltage synchronous drop and split-phase voltage drop, which achieves offline setting of voltage amplitude, frequency, drop time and online real-time parameter modification. The new device has perfected the cycle test function to meet the needs of different occasions. To develop a power electronic drop test device with the voltage dynamic drop time less than 10ms and the voltage harmonic content less than 3%, not only has the laboratory LVRT test been conducted, but also field test has been carried out in one thermal plant. The tests prove that the new device can overcome the limitations of the traditional testing devices, improve the testing efficiency and accuracy, and standardize the testing process [10-12].

2. Design of the testing device system for LVRT

2.1 Traditional test method

The test platform of the traditional low-voltage ride-through test device is shown in Figure 1. It is mainly composed of large power grid, speed control converter, digital oscilloscope and voltage drop device with multi-winding transformer structure. The experimental method will be adjusting the ratio to 1:1 of the voltage drop device, and keep K1 and K2 closed. The core controller controls the contactor to pull in or separate, and can therefore adjusting the number of turns of the secondary winding of the multi-winding transformer voltage drop device, and changes the output voltage of the secondary side. Due to the difficulty in accurately controlling the pull-in time and separating time as well as the input voltage amplitude, etc., the drop time and voltage amplitude are not accurate enough. Before each experiment, the oscilloscope is used to re-check.

![Figure 1. Schematic diagram of the testing platform for LVRT of the converter of traditional auxiliary motor](image)

3. The Electronic Testing System for Voltage Drop

The testing system for voltage drop based on power electronics is shown in Figure 2. It consists of a motor, a speed converter, a power electronic voltage drop device, and a large power grid. The power electronic voltage drop device is connected in series with the speed control converter and the large power grid and the drop device is in the middle. The power electronic voltage drop device is mainly
composed of three parts, the DC side, the input side and the output side, wherein the input side and the output side are four-bridge arm IGBT and filter reactors, and the DC side is composed of an electrolytic capacitor with regulated power supply.

![Control System Diagram](image_url)

Figure 2. Schematic diagram of the test platform for electronic LVRT testing

The testing device for the electronic voltage drop is designed to meet the testing requirements of both single-phase and three-phase converters. The three-phase four-wire system design not only satisfies the synchronous drop of the three-phase voltage on the output side of the device, but also any single voltage drop of the three phases. The input side is able to support not only the single-phase bridge arm to absorb the energy of the power grid and stabilize the DC-side voltage, but also the three-phase arms to absorb energy of the grid at the same time, in case of the single-phase overload, which improves the anti-overload operation capability of the equipment, promotes equipment flexibility, enhances field application capabilities, and improved equipment reliability [13-17].

3.1 The Design of the Adaptive PI Regulator

Collect the three-phase voltage $U_a(t)$, $U_b(t)$, $U_c(t)$ on the input side AC bus of the testing device for voltage drop, and then calculate the amplitude and frequency of the voltage, and by adaptive fuzzy PI adjustment, calculate the required output voltage amplitude and power. 16 pulse circuits are generated by the pulse generation module to control the four H-bridge operations. As shown in FIG. 4, the process includes a voltage amplitude comparison unit, use the voltage difference of the $U_a(t)$, $U_b(t)$ , $U_c(t)$, and $U_a(t)$, $U_b(t)$, $U_c(t)$ as the input of the adaptive PI regulator. The specific design scheme is as follows:

The adaptive fuzzy PI system is based on the premise of conventional PI control. By adopting the fuzzy reasoning idea, the error and rate of error change are used as the two inputs of the fuzzy controller. Then use the fuzzy rule to calculate the PID parameters through the fuzzy controller’s output variables, therefore optimize the PID parameters. Figure 3 shows the control system of the adaptive fuzzy PID.

![PID Control Structure](image_url)

Figure 3. Adaptive fuzzy PID control structure

The basic idea of fuzzy control is to adjust the two parameters in real time to meet different input error amount $e$ and error change rate $\dot{e}$, to ensure that the controlled object has good dynamic and static performance. First, the values of $k_p^*$ and $k_i^*$ are set according to the empirical values, and then the corrected values $\Delta k_p$ and $\Delta k_i$ are obtained by fuzzy inference, and the optimal $k_p$ and $k_i$ are obtained from the empirical value and the corrected value.

$$
\begin{align*}
  k_p &= k_p^* + \Delta k_p \\
  k_i &= k_i^* + \Delta k_i
\end{align*}
$$

(1)
In the above formula, \( k_p \) and \( k_i \) are the classical PI parameters of the system, and \( \Delta k_p \) and \( \Delta k_i \) are the adjustment values obtained by fuzzy inference. According to Figure 3, the optimization of the PI parameters is implemented according to the PI control formula:

\[
\Delta e(t) = e^*(t) - e(t) \tag{2}
\]

\[
\Delta u_a(t) = u_{a}^*(t) - u_a(t) \tag{3}
\]

Where \( U_a^*(t) \) is the voltage set value and \( U_a(t) \) is the voltage set value.

\[
\Delta u_b(t) = u_{b}^*(t) - u_b(t) \tag{4}
\]

Where \( U_b^*(t) \) is the voltage set value and \( U_b(t) \) is the voltage set value.

\[
\Delta u_c(t) = u_{c}^*(t) - u_c(t) \tag{5}
\]

Where \( U_c^*(t) \) is the voltage set value and \( U_c(t) \) is the voltage set value.

\[
u(t) = k_p \Delta e(t) + k_i \int_0^t \Delta e(t) dt \tag{6}
\]

Where \( k_p \) is the proportional coefficient; \( k_i \) is the integral coefficient.

The control system of the electronic testing device for LVRT is shown in Figure 4. The input side collects voltage, current, DC side voltage and other parameters in real time through the four-quadrant control module, calculates the difference of the DC side voltage, controls the magnitude and direction of the absorbed current on the input side, and stabilizes the DC side voltage. The output side collects the amplitude, frequency and phase of the three-phase voltage in real time by the acquisition unit.

The calculation unit, according to the amplitude and power of the set three-phase or phase-separated voltage, through the adaptive fuzzy PI regulator, enables the output side voltage amplitude and frequency parameters to dynamically track the set value in real time. This creates voltage sources that are able to have real-time regulation of the voltage amplitude, the frequency and the voltage drop time.

![Control system of test equipment for power electronic voltage drop](image)

**Figure 4. Control system of test equipment for power electronic voltage drop**

### 4. Device Development

#### 4.1 Device Parameter Design

As shown in Figure 5, the 30 kW voltage drop device is developed. The output side filter inductor is 0.2m H, the input side filter inductor is 0.15mH, and the DC side capacitor voltage is 650V. Both the input and output sides have an emergency stop switch, and the real-time interactive function of the upper computer is also available.
4.2 device function development

4.2.1 Development of The Upper Computer
The upper computer sets the control commands, parameter settings and display functions. The control commands include network side start/stop, AC side start/stop, fault reset, and operation mode. The parameter settings mainly include voltage and current protection settings, DC side voltage, output voltage amplitude, frequency, and so on. According to the power of the converter under test, set different protection settings, the upper computer interface displays the voltage, current, power values and wave-forms of each part.

4.2.2 Device protection setting
The device has perfect protection functions in case of AC side overvoltage, undervoltage, overcurrent protection, DC side overvoltage and overcurrent, and can shutdown in time when a fault occurs. As shown in Figure 6, the device is running stable. The output line voltage is 250V, the waveform is stable, and the harmonic content THD is less than 2%. The blue waveform is Uab and the red waveform is Ubc. As shown in Figure 7, the output voltage protection setting value is set to 320V. When the output voltage exceeds the protection setting value, the voltage drop test device automatically stops immediately for protection. As shown in Figure 8, the output side current protection setting is set to an effective value of 40A, wherein the green waveform is the A-phase current waveform. When the output current exceeds the protection setting, the testing device automatically stops immediately to protect the device.
5. Testing

5.1 Device Performance Test
The electronic testing device for LVRT performs frequency offset test, single-phase voltage drop test, 20%, 60%, 90%, 130% three-phase voltage drop test, in which the blue curve is the Uab line voltage and the red curve is the Ubc line voltage. It can be seen from Fig. 9 that the device output is stimulating the Uab voltage drop, and the dynamic response time is less than 5 ms. Figure 10 shows the waveform when the frequency offset of the voltage offset is 55 Hz, the voltage waveform is smooth, and the frequency is stable. Figure 11, Figure 12, Figure 13, and Figure 14 are test waveform diagrams of voltage drop of 20%, 60%, 90%, and 130% respectively. The waveform is dynamically switched at an instant of less than 5 ms, and the output waveform is standard without burrs.
Figure 9. Single-phase voltage drop waveform

Figure 10. Frequency change waveform

Figure 11. 20% voltage drop and recovery waveforms

Figure 12. 60% voltage drop and recovery waveforms
5.2 Field Testing
In a thermal power plant in Jiangxi, a field test for the LVRT of the low-voltage auxiliary machine converter was carried out, in which the measured converter power was 5.5kW, the three-phase output AC voltage was 342V-528V, and the maximum current was 14A. The power electronic voltage drop device sets the output line voltage to 380V, 20% voltage drop for 0.5s, 60% voltage drop for 5s, and 90% voltage drop for 60s.

Before the transformation of the low-voltage auxiliary machine converter, it can be seen from Fig. 15 that when the grid voltage is reduced to 90%, the DC side voltage of the converter drops to 488V, a drop of 16.6%. The converter voltage output is normal, and the output current vibrates at the moment of voltage drop and recovery, the converter does not issue a fault alarm, and the operation is normal. Figure 16 shows that when the grid voltage drops to 60%, the DC side voltage drops to 344V in 0.09s, the output voltage of the converter is 0V, the device shuts down, and after the grid voltage returns to normal, the converter restarts after 0.06s and sends out under voltage fault alarm. Figure 17 shows when the grid voltage drops to 20%, the DC side voltage drops to 328V after 0.09s, and the converter output voltage is 0V, the device shuts down. When the grid returns to normal, the converter does not recover, and send out an error alarm for automatic restart failure.
After the transformation of the low-voltage auxiliary machine converter, Figure 18a) is the waveform diagram showing the instant of the 90% voltage drop, Figure 18b) is the waveform diagram showing the instant of the 90% voltage recovery, Figure 18 shows the voltage waveform of the coal feeder converter when the voltage is temporarily reduced to 90%. From it can be seen that when the input voltage of the converter is reduced to 90%, the voltage drop time lasts for 10s, the converter output voltage drops by about 20V, the time for the drop and recovery response is 5ms, and the DC voltage has a small drop. The coal feeder system is operating normally. Figure 19a) is a waveform diagram showing the instant when 60% voltage drops, Figure 19b) shows the recovery instant of the 60% voltage. Figure 19 shows the voltage waveform of the coal feeder converter when the voltage is temporarily reduced to 60%. When the converter input voltage is reduced to 60%, the voltage drop time lasts for 10s, the output voltage of the converter drops by about 30V, the drop and recovery response time is 5ms, and the coal feeder system runs normally. Figure 20a) shows the time when the 20% voltage drop. Figure 20b) shows the instant when the 20% voltage recovers. Figure 20 is the voltage waveform of the coal feeder converter when the voltage is temporarily reduced to 20%. When the converter input voltage is reduced to 20%, the voltage drop time lasts for 10s, the output voltage of the converter drops by about 30V, the drop and recovery response time is 5ms, and the coal feeder system runs normally. Figure 21a) is the waveform portraying the 0% voltage drop. Figure 21b) is the 0% voltage recovery instant. Figure 21 shows the voltage waveform of the coal feeder converter when the voltage temporarily drops to 0%. When the grid voltage is reduced to 0%, the voltage drop time lasts for 10s, the output voltage of the converter drops by about 30V, and the coal feeder system runs normally. The yellow waveform represents the grid voltage, the red waveform is the output voltage of the coal feeder converter, and the blue one is the DC side voltage.
Figure 19. Voltage waveform of the coal feeder converter when the voltage is reduced to 60%:

- **a)** drop instant
- **b)** recovery instant
- **c)** the whole process of 60% voltage drop

Figure 20. Voltage waveform of the coal feeder converter when the voltage is reduced to 20%:

- **a)** drop instant
- **b)** recovery instant
- **c)** the whole process of 20% voltage drop
c) the whole process of 0% voltage drop

Figure 2.1. voltage waveform of the coal feeder converter when the voltage is reduced to 0%

6. Conclusion
The voltage drop device equipped with the power electronic full-control switching device and power electronic converter technology adopts fuzzy adaptive PI control to improve the output voltage response speed and high voltage output precision, avoiding the potential threat to the thermal power plant caused by the inrush current of the traditional test device. The electronic voltage drop device developed is easy to operate, small in size, light in weight and high in automation. The field test for the LVRT of the low-voltage auxiliary machine converter is carried out in a thermal power plant in Jiangxi, which shows that the output voltage is stable, the voltage dynamic response speed is high, the device meets the needs of field testing, and the field test results are satisfactory. The device can not only carry out tests for LVRT capability of low voltage auxiliary machine converter system in the power plant, but also achieve good economic and social benefits, and can also be promoted to other industries for low voltage frequency converter to carry out relevant tests.

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