Research and Application of Low Voltage Ride through (LVRT) and the Power Grid Adaptability Testing Device for Frequency Converter

Xu Zaidę¹, Liu Yang¹, Xu Jingmin¹, Xiao Qi², Zhu Zhijie²

¹The Electric Power Research Institute of State Grid Jiangxi Electric Power Ltd, Nanchang 330096, China;
²State Grid Jiangxi Electric Ltd, Nanchang 330096, China

Abstract: In order to study the response characteristics of converters applied in the field of renewable power integration and motor speed regulation when grid fault appears, the traditional LVRT schemes and effects of converters are analyzed, and the integrated design of AC and DC sources scheme based on power electronics technology is proposed. The three-phase four-wire topology AC and DC sources and adaptive fuzzy PI control algorithm is adopted to realize the real-time adjustment of the DC output voltage and dynamic control of the three-phase or single-phase AC output voltage. Meanwhile, the dynamic control includes the drop amplitude, the drop time, the frequency, and the Harmonic. The 40KW LVRT and grid adaptability testing device for converter is developed. The laboratory test proved that the dynamic response time of the device is less than 5ms, the harmonic content of the AC output voltage is less than 1%, and the protection mechanism is complete and reliable. The upper computer sets parameters offline or online, tests circularly and operates conveniently.

1. Introduction
Widely used in motor speed regulating system and renewable power integration field, the converter has obvious advantages in stepless speed regulation of motor, soft start of auxiliary machine and economical operation. At the same time, with the launch of the "photovoltaic poverty alleviation policy", three-phase and single-phase new energy grid-connected converters are connected to the power grid in abundance. New energy grid-connected converters and motor speed-regulating converters are carried out under the conditions of grid voltage drop, three-phase voltage imbalance and harmonic exceeding the standard. Therefore, it’s crucial to conduct research on the operational characteristics of the converters [¹].

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 motor converters. However, no research has been done on the testing device for LVRT of the converter [²-⁵]. When the grid fault appears, the new energy grid-connected converter has to face a series of problems such as rise of the current or DC-side capacitor voltage due to the accumulation of energy on the DC side of the grid, which seriously jeopardizes the safe and stable operation of converter itself and its control system. Beijing Jiaotong University, Shandong University, Harbin University of Science and Technology and other colleges and universities have conducted research on photovoltaic grid-connected converter and LVRT control strategy. That being said, the PV-connected converter LVRT test technology has not been studied in depth [⁶-⁸].
The Electric Power Research Institute of State Grid Jiangxi Electric Power Ltd has developed a test device for LVRT of the converters based on the development and study of power electronics technology for many years. The device comprises two parts: DC source and AC source. The DC source and AC source topology are all of three-phase four-wire bridge arm structure. The output DC voltage by DC source is continuously adjustable, and the AC source output voltage is equipped with the function of three-phase voltage synchronous drop or split phase voltage drop, which realizes the offline setting of the upper computer and the online real-time modification of the voltage amplitude, frequency and drop time, makes the harmonic superposition possible within 13 times, and ensures periodic cycle test. The traditional PI controller cannot guarantee the voltage amplitude steady-state accuracy and dynamic performance. This problem has solved by using adaptive fuzzy PI control strategy. In the laboratory test, the device proves the AC output voltage has a dynamic drop time of less than 5ms and the harmonic content is less than 1%. It can accurately simulate various operating conditions of the 380V low-voltage distribution network, and has capabilities to test the low-voltage riding-through and high-voltage riding-through of both AC and DC voltage, which improves test efficiency and accuracy, and helps standardize the testing process [9-10].

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 1a) and Figure 1b). It is mainly composed of large power grid, speed control converter/grid-connected 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 converter 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 and the magnetizing inrush current is generated during the transformer switching process, which result in certain risks for field testing, and it is difficult to simulate the distribution network with harmonics, frequency changes, voltage imbalance and other working conditions.

<Diagram a) Schematic diagram of the testing platform for LVRT of the converter of traditional motor>

<Diagram b) Schematic diagram of the testing platform for LVRT of the traditional grid connected converter>

Figure 1. Schematic diagram of the testing platform for LVRT

2.2 New Testing System for LVRT and the Power Grid Adaptability of converter
The new test device comprises two small-sized AC sources and DC sources. When the AC LVRT test is performed, the AC and DC source DC sides are connected respectively. Figure 2a) shows the DC
topology. Three-phase AC 380V input goes through the contactor K1, the charging resistor, and then through the filter L, to the four-quadrant rectifier module and becomes controllable DC voltage output; Figure 2b) is the AC topology, through the IGBT converter and the filter L, the controllable three-phase AC voltage is output.

![Diagram](image)

**Figure 2.** Electric and electronic type of topology

The new testing device for LVRT and grid adaptability of the converter is designed to meet the testing requirements of both single-phase and three-phase converters. 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, and realizes the dynamic adjustment of the DC side voltage. Meanwhile, the DC source is equipped with energy bidirectional control, which can charge or discharge the energy storage battery in the micro-grid, and can also simulate the DC voltage characteristics of the photovoltaic display. The AC voltage output can simulate the high-voltage, low-voltage, frequency offset, harmonic and other field conditions of the power grid, which helps to detect the anti-risk capability of the PV grid-connected converter under various working conditions. The structure of the three-phase four-wire back-to-back topology promotes equipment flexibility, enhances field application capabilities, and improved equipment reliability [11-13].

### 3. 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 LVRT and grid adaptability of the converter, 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. 3, 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.
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 \( e_c \), 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 formula above, \( k_p \) 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:

\[
\Delta e(t) = e^*(t) - e(t)
\]  

(2)

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

(3)

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

The control system of the new testing device for LVRT and grid adaptability is shown in Figure 4, wherein the dotted line on the DC side is the connection position of the two sets of AC-DC devices. 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, the voltage drop time, the harmonic superposition times, and power factor. The upper computer setting mainly completes the protection of the parameter setting and the modification of the specific experimental parameters.
4. Device Development

4.1 Design of the Device Parameters
The aim is to develop 40 kW testing device of the LVRT and grid adaptability of the three-phase four-wire converter, with the output side filter inductance reaching 0.2m H, filter capacitor 44uF, switching frequency 12kHz, rated AC input voltage 380V, dynamically adjustable DC output voltage 0-850V, dynamically adjustable AC output voltage 0 -520V. The input and output sides both have an emergency stop switch, and the real-time interactive function of the upper computer is also available.

4.2 Development of the Device Functions

4.2.1 Development of The Upper Computer
The upper computer sets the control commands, parameter settings and display functions of the DC system and the AC system. The control commands include DC 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, harmonic content, 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 Protection Setting
The device has perfect protection functions in case of AC side overvoltage, under voltage, overcurrent protection, DC side overvoltage and overcurrent, and can shut down in time when a fault occurs. As shown in Figure 5a), the output voltage protection setting effective value is set to 320V. When the output voltage exceeds the protection setting value, the test device automatically makes the output contactor separate. As shown in Figure 5b), the output side current protection setting is set to an effective value of 40A, wherein the green waveform is a phase A current waveform, and when the output current exceeds the protection setting, the test device automatically shut down for protection. As shown in Figure 6a), the DC voltage protection setting effective value is set to 680V. When the DC voltage reaches 679.1V, the DC side contactor is tripped. As shown in Fig. 6b), when the DC side is used as the power source, set the effective value of the absorption grid current protection setting to 20A. From the waveform, it can be seen that when the current peak value reaches 28A, its protection system automatically responds to the current fault occurs, which shows that the actual value is similar to the theoretical calculation value.

5. Testing

5.1 Performance Testing
The testing device for LVRT and grid adaptability of frequency converter can carry out DC voltage
drop test, DC dynamic response test, AC frequency offset test, single-phase voltage drop test, 20%, 60%, 90%, 130% three-phase voltage drop test, and harmonic superposition test, in which the blue curve is the Uab line voltage and the red curve is the Ubc line voltage. Figure 7a) is a voltage dynamic output process in which the DC output voltage is gradually increased. Figure 7b) shows that the DC voltage is switched from 760.5V to 614.6V, the voltage drop amplitude exceeds 150V, and the dynamic response time is 25.6ms. Figure 8a) shows that the Uab line voltage set by the upper computer have decreased from the 380V to 190V for 0.2s. Figure 8b) shows the waveform of the condition when the voltage drop of the Uab line while the other voltage remains normal. Figure 9a) The three-phase voltage set by the upper computer dropped from 380V to 76V, and the drop continues for 0.2s. Figure 9b) shows the waveform output by the three-phase AC voltage drop. Figure 10a) is waveform when the offset frequency of the output voltage is 45Hz, 10b) presents the waveform when the frequency offset of the output voltage is 48Hz, 10c) is waveform when the offset frequency of the output voltage is 50Hz, 10d) is the waveform when the offset frequency is 65Hz, which shows the voltage waveform is smooth, the frequency is stable. Figure 11, Figure 12, Figure 13, and Figure 14 are test waveform diagrams when the voltage drop is 20%, 60%, 90%, and 120% respectively. The waveform is dynamically switched at a switching instant of less than 5ms, and the output waveform is standard without burrs. Figure 15a), Figure 15b), Figure 15c), Figure 15d) are waveform diagrams when the device is injected 5% fifth harmonic, 5% seventh harmonic, 5% fifth harmonic and seventh harmonic, 5% thirteenth harmonic respectively. This realizes the stimulation of the working condition of various harmonics in the field by the output voltage.
a) drop parameters set by the upper computer  
b) three-phase drop output waveform  

Figure 9. The waveform of three-phase voltage drop

a) 45Hz  
b) 48Hz  
c) 50Hz  
d) 65Hz  

Figure 10. Frequency change waveforms

a) voltage drop  
b) voltage recovery  

Figure 11. 20% voltage drop and recovery waveforms

a) voltage drop  
b) voltage recovery  

Figure 12. 60% voltage drop and recovery waveforms

a) voltage drop  
b) voltage recovery  

Figure 13. 90% voltage drop and recovery waveforms
6. Conclusion

The power electronic full-control switching device and power electronic converter technology are used to develop the LVRT and the grid adaptability testing device for the frequency converter. The AC voltage can simulate not only the simultaneous drop of the three-phase voltage, arbitrary phase voltage drop, frequency offset, harmonic superposition, etc. but also the photovoltaic array and charging and discharging characteristics of DC battery by the DC voltage. The control strategy adopts adaptive fuzzy PI control, which improves the response speed of the output voltage, voltage output precision, and provides a wide application field. It can not only test the traditional motor speed converter, but also apply to the new energy grid-connected converter. Simulate various faults of the distribution network by matching different parameters, and detect the response of the converter when grid fault occurs. Research and develop the testing device for LVRT and grid adaptability of the frequency converter by using the upper computer to set parameters, achieving high degree of automation and convenient operation. The device comprises two parts. Small and light in weight, the device has gone through the laboratory test, and has been proved that its output voltage is stable, its voltage dynamic response speed is high, which satisfies the requirements of field testing. By great performance in the field test, the new device shows its strong practicability and promising promotion prospects.

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