Test Device of UHV Transformer's AC Withstand Voltage and Partial Discharge (PD) Tests

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Abstract: This paper summarizes research status of test device of UHV transformer's AC withstand voltage and PD test; Referring to 1000kV transformer test data from UHV test base of Wuhan High Voltage Research Institute, testing method and test circuit are proposed, which are applied in AC withstand voltage test and PD test on UHV device. Design methods of variable frequency power source and high-voltage reactor in the device are discussed. The paper also proves the rationality of test device and test method by analyzing the data from AC withstand voltage and PD test on 750kV transformer, and also demonstrates that test device has high stability, good security, strong practicability and good potential in application.

Key words: UHV transformer, AC withstand voltage, PD, power transformer

Introduction

With rapid growth of electric load, it is urgent to increase super-high and UHV grid for long and high-capacity power transmission. In the ultra-high system, electric equipment is its core part. Smooth transmission of electric energy relies on reliable operation of electric equipment. The production department of electric equipment carries out strict delivery test when they leave factory. Because of large volume, equipment must be disassembled to small units, transported to site and then assembled on site. Therefore, it is very important to conduct the test on site. On the one hand, it needs to check whether the equipment is correctly installed; on the other hand, it is vital to check whether the equipment is broken or damped during the transportation. AC withstand voltage and PD test of electric equipment is an effective method, which reflects insulation condition of electric equipment. AC withstand voltage test reflects withstand capacity and voltage withstand level under normal condition; PD test is used for measuring PD level when electric equipment exceeds operation voltage and can correctly reflect health condition and aging degree.

In the super-high voltage and UHV system, resonant test system or medium-frequency generator is mostly adopted to conduct AC withstand voltage test and PD test for high voltage electric apparatus. A whole set of device is yet used to conduct AC withstand voltage test and PD test. At present, resonant test system without PD cannot conduct

transformer test; concerning medium-frequency generator, output frequency is single, which can only meet the requirements of AC withstand voltage test and PD test of power transformer. However, this mode has disadvantages such as large size, high production cost, long production cycle and not easy to transport etc. In view of the above situations, the paper puts forward a new kind of AC withstand voltage and PD test device for UHV electric apparatus. This new device is small and its frequency can be adjusted. It is suitable for various test objects and can be used on site.

1. Test Principle

The method of applying voltage -- low voltage induction is adopted to conduct AC withstand voltage test and PD test for UHV power transformer. In other words, its own turn ratio of transformer is utilized to raise the voltage at the low voltage side and then induce out high voltage at the high voltage side. The test principle is shown in Fig.1(in the next page).

Take AC withstand voltage test and PD test conducted by Wuhan High Voltage Research Institute in China for the first time as an example to verify that this test principle is correct. Equipment parameters used in the test are shown in Tab.1. In the Tab.1, relative humidity is 78%; test object is 1000kV main transformer B phase of ultra-high base of Wuhan High Voltage Research Institute; test content is to conduct AC withstand voltage test and PD test on 1000kV transformer.

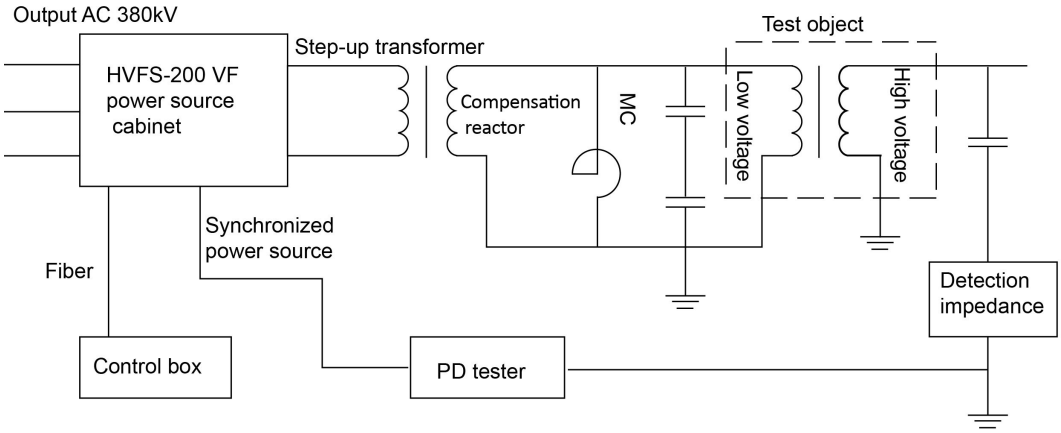
Tab.1 Parameter of each part used in the Fig.1

Part name	Parameter of each part	
Variable frequency power source	rated power/kW	400
	rated output current/A	1142
	waveform distortion rate/%	＜3
	rated output voltage/A	0-350
	frequency adjust range/Hz	20-300
	weight/t	1.8
Step-up transformer	rated capacity kV.A	400
	rated voltage kV	2×40
	short-circuit impedance /%	5
	weight/t	1.8
Compensation reactor	rated voltage/kV	40
	rated current/A	30
	rated capacity kV.A	1200
Measurement capacitance	rated voltage/kV	100
	capacitance	1000
	rated voltage ratio	1000:1
	measurement error	2
	introduced loss	0.1
	rated voltage/kV	1050/35
	rated current/A	60/1142

Test object DZ-40000/1000	rated capacity MV.A	40
	Short-circuit impedance %	9
	no-load current %	0.11
	Insulation level/kV	AC 2250/1800/1100

Power source current/A	421.0	531.0
Low-voltage side current/A	15.0	25.0
PD level/pC	44.0	98.0
Compensation reactor current/A	11.0	19.0
High-voltage side current/A	0.2	0.3

Fig.1 Schematic diagram of AC withstand voltage and PD test



According to GB 1094.3-2003, AC withstand voltage test is conducted while measuring the quantity of partial discharge. In addition, AC withstand voltage test and PD measurement are carried out in sections. Data of each section is shown in Tab.2.

Data of the first domestic UHV transformer's AC withstand voltage and PD test

Measurement at each section	Test voltage 1.10 *U*m	Test voltage 1.31 *U*m
Power source voltage/V	395.0	391.0

The above data illustrates that power source with small capacity can be used to finish the test when test circuit put forward by this paper is used.

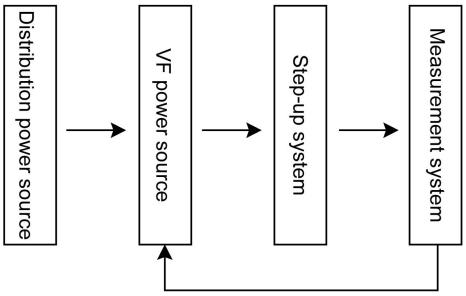
2. Analysis of Technical Performance of Variable Frequency Power Source

With regard to conducting AC withstand voltage test and PD test for UHV power transformer, key point is how to obtain high voltage power source, which is higher than ultra-high voltage.

The purpose of obtaining high voltage power source is to make UHV power transformer bear the voltage, which surpasses rated voltage, within short time and examine the capability of

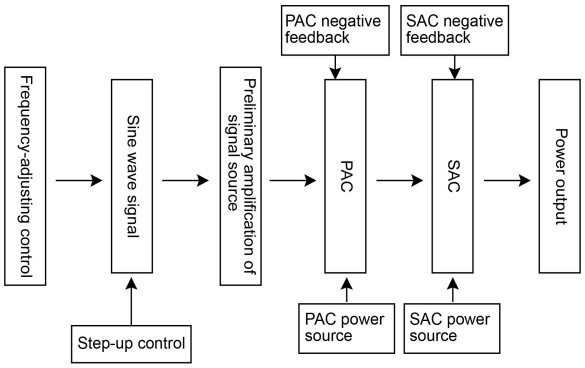
bearing over-voltage. Solution can be expressed in three aspects. ① Because total voltage comes from low-voltage distribution power source, it is necessary to avert distribution power source to controllable low-voltage power source with large capacity; this power source can regulate the frequency and voltage, and is free of high-frequency interference; ② A device is needed to raise the voltage, that is, raise low voltage power source to needed voltage; ③ Parameters should be measured, such as test voltage, current, PD level and frequency. Process is shown in Fig.2.

Fig.2 Flow chart of obtaining high-voltage power source



In the Fig.2, variable frequency power source can be obtained through power and electronic technology and can conduct microcomputer measurement and control. Circuit process is shown in Fig.3. From Fig.3, we can learn that variable frequency power source is in fact a kind of power amplifier. It can make weak and variable standard sine-wave signal realize high power output by step-by-step amplification. That means it turns into power source device, whose power reaches thousands of Watt. In the power amplifier, distortion degree of sine-wave signal is small. In addition, the frequency can be adjusted and we can also adjust output voltage at the same time.

Fig.3 Flow chart of variable frequency power source circuit



In the amplifier, power of each section obtains the signal from the previous grade and amplifies via DC power source. The whole amplifier is divided into 3 grades: preliminary amplification, primary amplification and secondary amplification. Preliminary amplification only amplifies sine-wave signal, and the power that the signal gets is very low; in addition, output voltage is also low and this part can complete the regulation of frequency and voltage; primary amplification further amplifies the signal. Primary amplification circuit finishes output from signal source to initial power; its output power is very low ($<$ 100W) and easy to regulate and step up the voltage; secondary amplification circuit is main circuit and finish power amplification via a large number of high-power shunt triodes after receiving the signal. We use many elements in the circuit and the circuit is very complex, so key point lies in reasonable layout.

3. Analysis of Technical Performance of High Voltage Reactor

Oil-immersed high voltage reactor and hollow coil are generally adopted to ensure that PD level of reactor cannot affect PD measurement of test circuit. Shunt compensation high-voltage reactor is adopted for conducting PD test. Its characteristics are as follows: ① Low rated voltage. Shunt compensation reactor runs at the low-voltage side of power transformer. Since the voltage of test object is relatively low (rated voltage is 110kV), the voltage of shunt reactor does not need to be high; ② Large capacity. Because of ground capacitance, compensation reactor must have 2 times of test object capacitance; ③ Several reactors run in parallel. On the one hand, compensation current can be raised; on the other hand, the size per unit is reduced for transportation; ④ Long working time. It takes over one hour to measure PD per phase and the reactor is very hot. When another phase test is being conducted, inner temperature of reactor does not reduce completely. Full-load work time is over 3 hours.

4. Simulation of on-site Test

Prototype is produced based on actual conditions of the project and theoretical analysis. In particular, it must be designed in strict accordance with product codes. 750kV power transformer is selected to test in the ultra-high test base in order to calibrate design rationality. According to standards, long-time AC withstand voltage test is conducted while measuring the quantity of partial discharge. In addition, AC withstand voltage test and PD measurement are carried out in sections. Test circuit parameters are shown in Tab.3. Measurement data of each section is illustrated in Tab.4. In the Tab.3, relative humidity is 58% and the temperature is 27℃; test object is A phase of No.1 main transformer in the Qinghai Guanting 750kV substation; test content is to conduct AC withstand voltage test and PD test on 750kV transformer.

Tab.3 Parameter of each part used in the Fig.1

Part name	Parameter of each part	
Variable frequency power source	rated power/kW	400
	rated output current/A	1142
	waveform distortion rate/%	＜3
	rated output voltage/A	0-350
	frequency adjust range/Hz	20-300
	weight/t	1.8
Step-up transformer	rated capacity kV.A	400
	rated voltage kV	2×60
	short-circuit impedance /%	6
	weight/t	5
Compensation reactor	rated voltage/kV	60
	rated current/A	30
	rated capacity kV.A	1800

Measurement capacitance	rated voltage/kV	100
	capacitance	1000
	rated voltage ratio	1000:1
	measurement error	2
	introduced loss	0.1
Test object ODFS-500000/750	rated voltage/kV	765/$\sqrt{3}$/345/$\sqrt{3}$/63
	rated current/A	1132.1/2381
	rated capacity MV.A	500
	Short-circuit impedance %	9
	no-load current %	0.053
	Insulation level/kW	92.8

Tab.4 Data of 750kV transformer's AC withstand voltage and PD tests

Measurement at each section	Test voltage 1.5Um/$\sqrt{3}$	Test voltage 1.7Um/$\sqrt{3}$
Power source voltage/V	383.0	376.0
Power source current/A	551.0	731.0
Low-voltage side current/A	28.0	35.0
PD level/pC	40.0	92.0
Compensation reactor current/A	21.0	29.0
High-voltage side current/A	0.2	0.3

According to Tab.3 and 4, AC withstand voltage and PD test of power transformer designed by the author can operate smoothly on site and solve the problem of high power. The highest voltage of test object reaches 765kV during the test and is $\sqrt{3}$ times of operating voltage. Meanwhile, it can work for a long time and completely measures the quantity of partial discharge. Also the AC withstand voltage test is conducted, which provides references for conducting UHV electric equipment test in future.

PD measurement shows the effect that the whole device has on PD measurement of test object. When the voltage is $1.5U_{\mathrm{m}}/\sqrt{3}$, less than 50pC PD can be distinguished, which means that it is possible to conduct the measurement of UHV power transformer.

5. Conclusions

(1) Having designed parameters of AC withstand voltage and PS test device of UHV power transformer.

(2) Combined with modern electronic technique, function of variable frequency and voltage regulating is realized via amplification of high-power shunt triodes, which

provides super-high power source needed by on-site test of electric project.

(3) AC withstand voltage test and PD test of domestic 750kV super-high power transformer are successfully conducted via prototype.

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