Analysis of Variable Frequency Resonant Withstand Voltage Test for 220kV Long Cable On Site

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Abstract: Newly-completed 220kV cable line in the eastern urban area of Jinan city is 7.97km and has large capacity. If we want to carry out withstand voltage test, power source capacity, maximum output total current, weight of needed test equipment must be minimized and easy to install. This is the first time that such high-voltage test has been conducted in Jinan. After comparing all available methods, serial variable frequency resonant withstand voltage test is adopted. Based on theoretical calculation and analysis, reasonable test scheme is put forward and implemented smoothly. Finally, we make discussions combing with test results. Practice has proved that resonant test system is workable and effective and is of important value for variable frequency resonant withstand voltage test for long power cable on site.

1. Introduction

Conducting effective cable hand-over test on site can reduce the probability of breakdown to largest extent and ensure reliable and safe cable operation. However, the capacity of cable is great, especially long cable, traditional test methods cannot meet the requirement of field test. At present, There is a lack of long and high-voltage cable hand-over test in China.

1) Super-low frequency (0.1Hz) withstand voltage test is mainly applicable to medium-low voltage XLP insulation cable withstand voltage test.

2) Power frequency AC withstand voltage test needs large-capacity test equipment. The equipment weighs several tons and huge in size and difficult to assemble. This type of test cannot meet the requirement of field test.

3) Variable frequency resonant test utilizes the principle of variable frequency resonance to reduce power source capacity to 1/Q of test object capacity. Great fall in equipment weight makes it possible to conduct high-voltage and long cable field test. Meanwhile, test frequency and test reactor can be adjusted, adding system flexibility.

The test object in this paper is 7.9km cable; test current is high; Q value of test equipment requires to be high. Against the above problems, the paper deeply analyzes some problems, which may occur during the test, and puts forward test scheme. According to test results, test frequency and test object length are analyzed, which is of important reference value. Test object is a municipal engineering cable, which is located in the eastern urban
II. Test Parameter Analysis

1. Principle of variable frequency series resonance

The voltage of circuit input end $U$ is the same phase with current $I$. Schematic diagram of series resonance is shown in Fig.1.

$$Q = \frac{\omega_0}{R} = \frac{1}{R} = \frac{L}{\sqrt{LC}} = \frac{1}{R \sqrt{C}}$$

(3)

The resonant withstand voltage test makes the circuit in resonant condition via changing inductance of test system and test frequency. Most capacitive current on test object is offset by reactive current on the reactor in the test circuit. Power source only provides the energy for active power consumed in the circuit. However, both end voltage $U_{CX}$ of test object $C_X$ is $Q$ times of power source voltage $U_S$, $U_{CX} = QU_S$. $Q$ is resonant multiple of the system, namely, quality factor.

2. Test parameters

According to GB 50150-2006 Standard for Hand-over Test of Electric Equipment Installation Engineering, 220kV cable field AC withstand voltage test requires 1.7 times of rated phase voltage; frequency ranges from 20Hz to 300Hz; test time is 60min. Schematic diagram of test scheme is shown in Fig.2.

![Fig.2 Schematic diagram of test scheme](image)

FC: Variable frequency source
$T_r$: Exciting transformer
$L$: Reactor
$C_x$: Test object capacitance
$C_1$ & $C_2$: high voltage divider

1) Test object parameter
2) Test voltage
\[ U = 1.7 \times U_r = 216kV \]

3) Capacitance
\[ C_x = 1.87uF. \] Since test object capacitance is high, frequency should be low to make test current within the acceptable range: 30Hz.

4) maximum total current under 30Hz test voltage is \[ I_x = \omega C_x > = 76.10a \]

5) Exciting voltage
Series resonant condition, \( Q_0 > 40 \), \( U_l > U / Q_0 = 5.4kV \)

6) Power
\[ Q = 15.82Mvar \]
\[ P = Q / Q_0 = 395.5kW \]

Through above calculation, we learn that test object capacitance is great; test frequency should be low; total current should be high; \( Q \) value requires to be higher.

3. Capacitance rise of test object

According to GB/T 16927, capacitance rise ratio of AC withstand voltage test should not be more than ± 3%. Hence, it is necessary to reasonably configure test equipment and reduce capacitance rise of test object. Schematic diagram of 220kV cable AC withstand voltage test is shown in Fig.1. The test object takes on capacitive condition during the test.

Frequency of resonant test system is 50Hz, \( X_i = 1.14 \Omega ; X_c = 1703 \Omega \); the ratio of capacitance rise to voltage is about \( X_i / X_c = 0.07% \);

Based on theoretical calculation, if AC withstand voltage test frequency ranges from 30Hz to 50Hz, the ratio of capacitance rise to voltage is between 0.024% and 0.07%, which conforms to the requirements of GB/T 16927. Hence, it is not necessary to set remote reactor. However, at the moment of voltage up, it is likely that transient process causes instantaneous over-current. Voltage divider can be installed at both ends to monitor and prevent the voltage from being too high.

III. Field Test Case

1. Test scheme

Main characteristics of this test are as follows: ① maximum total current is high and even reaches 76.1A ② test object capacity is great - 1.87uF. German Hyva RSE 400 on-board resonant test system device: dimension 16m×2.5m×4.1m (L×W×H); capacity 21580kV·A; maximum output current 83A; frequency range 20-300Hz. Device test voltage basically meets the requirement. Picture of real device is shown in Fig.3.
Because of on-board type, test device is far lighter than assembled device and its installation is simplified on site. Because $Q$ value is high, it can meet the requirement of this test under the available environment condition (temperature: 0-7 ℃; humidity: 30%-50%).

According to on-site measurement results, needed current of input power source is 400A. The power van in this test adopts 1000kV·A capacity; current is close to 1100A; there are also one 5000W generator and one 1000kV·A generator group, which conform to test requirements.

2. Test Site Preparation

1) One end of test wire is connected to transformer or reactor while the other is connected to wire clamp on test object cable terminal. Dangling part of wire must be higher than 2200mm from the ground. High voltage wiring is shown in Fig.4.

Fig.4: High voltage connection

2) Capacity of power van is 1000kV·A. Objects around the test vehicle is centered on the vehicle and safety radius is 5m, which is shown in Fig.5.

Fig.5 Diagram of test vehicle safety distance

(3) Test Conduction

We should be slow to raise the voltage during the test. Otherwise, it will affect test equipment. When breakdown of test object occurs, high voltage disappears at once because of losing resonant condition, which is not helpful for recording test object breakdown voltage. If too slow, it will have effect on test schedule. Procedures of this scheme are as follows:

1) Start power van; open power source switch of test equipment
2) Raise the voltage; speed remains at 10kV/10s; stop for 30s per 10kV voltage rise until 216kV; keep the voltage stable and test time lasts 60min.
3) Inspect the whole device to learn operation condition and examine whether test frequency variation meets the requirements.
4) After completing the test, the voltage gradually falls to zero and grounds after discharge.

IV. Analysis of Field Test Results

Data screen-shot during the test is shown in Fig.6.

Fig.6 Test process photo

From Fig.6, high $Q$ value is 144; resonant frequency keeps at 28.97Hz
at last, which is close to 30Hz; test current gradually rises to 76.1A, which is in line with theoretical calculation; displayed value of applied voltage on head end is 224.4kV and error calibration coefficient is -4.3%; namely, actual voltage of head end is $224.4kV \times 0.957 = 214.7kV$; tail end voltage is 211.2kV; error calibration coefficient is 1.4%; actual voltage of tail end is $211.2kV \times 1.014 = 214.2kV$; capacitance rise conforms to the range requirement - $\pm$ 3%. The calculation value is close to actual measurement value. Test voltage raising curve is shown in Fig.7.

![Test voltage raising curve](image)

V. Conclusions

The paper selects suitable test scheme and combines test results to make the following conclusions.

1) Test mode. Practice has proved that resonant test system is a workable mode for long and high voltage cable. The key point lies in reasonable configuration and selection of available test equipment if you want the test to be successful. According to GB 50150-2006 standards, above cable line test is conducted and test results indicate that this line conforms to standard requirement.

2) Test frequency. Digging through relevant technical materials at home and abroad, it is still an important issue to select suitable test device and power frequency test transformer to obtain reasonable weight and frequency range. Based on this test, if the cable is longer and capacitance is greater, needed output current is higher. Hence, long cable test should reduce the resonant frequency of test equipment in order to reduce test current.

3) Maximum length of test object. Great capacity is one of remarkable characteristics for test object cable. In the test, test object is 7.9km long. When the frequency is 30Hz, maximum total current has been close to upper limit of test equipment. If frequency and unit capacitance remain the same, theoretical maximum length is 8.67m.

Many tests, such as 220kV Xingyao I, 220kV Xingyao II, 220kV Yaowen cable and 220kV Xingyao test, have proved that series resonant withstand voltage test scheme is workable and practical and is of vital significance to full-scale operation of relevant tests all over the nation.

REFERENCES


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