Application of the technology about frequency conversion resonance in cable test

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Abstract. According to the introduction about technology of the frequency conversion and structure of the device, In this paper, we know that the application of new reactor plays an important role in the test of XLPE cable and other equipment with operating voltage of 110kV and has high efficiency, we also elaborate characteristics of the test device about frequency conversion resonance combined with practical application

1. Introduction
XLPE cable has been widely used because of its good insulation and mechanical properties, what's more, it also has the feature of convenient installation and maintenance, especially low failure rate when it is in running. But what our common concern is that whether using DC or AC test method when we doing test of installation and prevention about the XLPE cable. Since the end of 1990s, Guangdong, Beijing and other places in China have issued Provisional Regulations about AC test for XLPE cable. Combined with the test procedures formulated by other provinces and regions, the test of withstanding AC voltage for XLPE cable has became a consensus with the promulgation and implementation of China's national standard GB50150-2016 Standard of handover test for electrical equipment.

2. Applications and characteristics about the test of frequency conversion and resonance.
Frequency conversion and resonance is mainly used for on-site withstanding AC voltage test on the electrical equipment which has high capacitance, such as XLPE cable which is used for various voltage levels, GIS, Stator of generator.

Power frequency is the best when doing handover or preventive test on large capacity transformer and some related electrical equipment. The capacity of capacitance on testing instrument is so large that it cannot be used for on-site test, what's worse, high power is also needed. According to the guidelines for the acceptance test of high voltage extruded insulation which is published by the working group of CIGRE in 1997, The frequency between 30-300Hz and the power frequency can be equivalent well on the test of withstand voltage. This method is recommended for cable test and the voltage standard of cable test is established.

It has characteristic of good equivalence, high efficiency, and the equipment used for testing is so light that it can be convenient to carry, what's more, the length of the test equipment can be shorter and shorter, based on large number of the simulated test and research on related theories form some university laboratories, as well as the experience of frequency conversion test in foreign countries for more than ten years. IEC60840 add AC test of 1.7u0/5min or 1u0 / 24h to the standard of test for cable
which is installed and the voltage level is between 45-150kV. IEC 62067 puts forward requirement of
the frequency on AC cable test for 220kV level, which is between 20-300Hz.

3. Theory of series frequency conversion resonance

Definition of resonance: the phase of input voltage and current which in circuit are the same. It is
usually divided into series resonance (voltage resonance) and parallel resonance (current resonance).

![Figure 1. principle diagram of series resonance](image)

Table 1. Frequency conversion and resonance is mainly used for on-site withstanding AC voltage test
on the electrical equipment

| NO. | Item                          | Test for withstand voltage in power frequency | Frequency conversion resonance(30Hz-300Hz) | Extremely low frequency(0.1Hz) | High voltage (DC) |
|-----|-------------------------------|---------------------------------------------|------------------------------------------|---------------------------------|-------------------|
| 1   | Equivalence about power frequency | best                                       | best                                    | better                          | poor              |
| 2   | Successful probability about faulty check | highest                                   | highest                                  | higher                          | lower             |
| 3   | Degree of destruction about tested equipment | low                                        | low                                     | lower                           | highest           |
| 4   | Volume of test equipment      | larger                                     | small                                    | small                           | smallest           |
| 5   | Voltage of the test           | low                                        | power frequency                         | high                            | high              |
| 6   | Time of the test              | 1min                                       | 5-15min                                  | 45-60min                        | 5min              |

Conclusion / Cannot be used in on-site test
High feasibility and excellent
Cannot be used in on-site test for high voltage
Forbidden

Resonant frequency: \[ f_0 = \frac{1}{2\pi \sqrt{LC}} \]

Resonance angle frequency: \[ \omega_0 = \frac{1}{\sqrt{LC}} \]

Definition of quality factor in circuit: the ratio of the capacity obtained by the test object to the
output capacity of the excitation transformer. Series resonant circuit can be replaced by the ratio of the
voltage value on the test object to the output voltage of the excitation transformer, and parallel
resonant circuit can be replaced by the ratio of the current of the test object to the output current of the
excitation transformer.

\[ Q = \frac{\omega_0 L}{R} = \frac{1}{R} \times \frac{1}{\sqrt{LC}} = \frac{L}{R \sqrt{C}} \]

Characteristic of the circuit during resonance:
The Min- impedance: \( Z = R \), and the current reaches Max when the value of voltage is invariant \( (I_0 = \frac{U}{R}) \); the value of voltage at both ends of the capacitor is \( Q \) times of the power supply \( (UC = QU) \); the power of source is: \( P = UI = \frac{U^2}{Q} \cdot 1 \); it can be seen that the excitation power of the source is only \( 1/Q \) of the \( C \) when resonance occurs, and the greater of the \( Q \), the better.

The test device can make inductance and capacitance reach a resonant state by adjusting the frequency of power supply or inductance. As shown in Figure 2, frequency conversion resonance device in series makes the circuit in a resonant state by changing inductance and frequency. The series resonance, also known as voltage resonance, is selected for that it is mainly to check the withstand voltage of the tested object. The technology of frequency conversion resonance reduces the capacity of the test power supply, and the weight of the equipment can be greatly reduced, so that it is convenient to on-site test. For example.

![Figure 2. principle diagram of wiring about series resonance](image)

**Definition of Variable Frequency power supply:** the frequency of the power supply which can be adjusted continuously. DL849.6-2004 general technical requirement about appropriate test instrument for power equipment - test device in high voltage and resonance state stipulates that the frequency of power source can be continuously adjusted from 30 to 300Hz. Generally, it has several specifications, such as 5kVA, 10kVA, 20kVA, 50kVA and so on.

**Definition of Excitation Transformer:** the transformer used to provide energy for the resonance system, such as inductance and capacitance. Combined with power supply which can change frequency, the core of this transformer can be suitable for the voltage response under a wide frequency. Generally, it has several specifications, such as 5kVA, 10kVA, 20kVA, 50kVA.

**Definition of Resonance Reactor:** it is used for resonance with the capacitance from the tested object, aims at obtaining high voltage (or current). 1-3 reactors are connected in series or parallel according to the requirements. It has several specifications, such as 30h / 20kV / 2a, 40h / 40kV / 3A.

**Definition of capacitance voltage divider:** it can measure accurately \( (\pm 1\% ) \) for the voltage of the tested equipment. Range has 100kV, 150kV and so on.

**Definition of compensatory capacitor:** In order to ensure that the resonance frequency is within the range required by the regulation when doing withstand voltage test for large-scale transformer or generator, compensatory capacitor is often used to increase the capacity of the tested equipment (part of dotted line, shown in figure 2), but this device is not needed in cable withstand voltage test just because of its own large capacitance.

### 4. Precautions for on-site

We should fully understand the voltage degree, length and cross-sectional area of XLPE cable before test, and the total capacity of the tested cable shall be calculated by consulting table of instructions \( (\mu F/km) \). For example, the specifications of the cable are: 8.7/10kV, 300mm² and 5km. According to the table, the per kilometer cable of the capacitance is 0.37\( \mu F \), then \( C = 5 \times 0.37 \mu F/1\text{km} = 1.85 \mu F \).
Table 2 Capacitance per kilometre of the XLPE cable  Unit: μF

| Sectional area of the cable (mm²) | YJV | YJV | YJV | YJV | YJV | YJV | YJV |
|----------------------------------|-----|-----|-----|-----|-----|-----|-----|
|                                  | YJV | YJV | YJV | YJV | YJV | YJV | YJV |
| 6/6k V 8.7/10k V                 | 0.358 | 0.284 | 0.241 | 0.164 | 0.153 | 0.128 | 0.123 |
| 6/10k V 8.7/15k V               | 0.388 | 0.307 | 0.267 | 0.18 | 0.163 | 0.138 | 0.132 |
| 3×150                           | 0.43 | 0.339 | 0.291 | 0.194 | 0.176 | 0.156 | 0.146 |
| 3×240                           | 0.472 | 0.37 | 0.319 | 0.211 | 0.19 | 0.168 | 0.157 |
| 3×300                           | 0.514 | 0.396 | 0.331 | 0.224 | 0.202 | 0.18 | 0.168 |

The resonance frequency is estimated by the principle of lower frequency and small current of the test \((I=2\pi fcU_{test})\). If the reactor is connected in series, the inductance and withstand voltage will increase, and it is suitable for short cable; otherwise, if the reactor is connected in parallel, the inductance will decrease but the withstand voltage will not change, and it is suitable for long cable. It is estimated that by the number of reactors (1-3 groups) equipped with the test device:

\[
F_0 = \frac{1}{2\pi c} \cdot \frac{1}{\sqrt{L/C}}
\]

The total inductance is \(L = 10H / 3 = 3.33H\) if three reactors are connected in series and each inductance is \(L = 10H\), then \(F_0 = 64.156Hz\). Whether the reactor and excitation transformer can bear or not by estimate the value of the test current: \(I=2\pi fcU_{test}=12.969A\) (we can see that the current of reactance and excitation transformer are not satisfied). The test can be carried out normally if both of them can meet the requirements.

There are three ways to connect light reactors (take the voltage of “10 / 35kV” for example):

![Figure 3. Wiring diagram of the test equipment for small capacitance](image-url)
a. Placement (6 reactors in series) and wiring diagram which is used for the cable test of short length.

b. Placement (3 reactors in parallel and 2 reactors in series) and wiring diagram which is used for the cable test of medium length.

c. Placement (6 reactors in parallel) and wiring diagram which is used for the cable test of long length.
According to the latest national standard from China, the test time for handover about the core, which the voltage is above 35kV, should take one hour. Here is a brief describe about the wiring and configuration about the long-time time. As shown in Figure 6, There is a high withstand voltage(20kV) radiator in the bottom of the reactor(necessary), and a wind shield is on the top. The wiring is 4 in series and 2 in parallel: 1-3-5-7 are in series, so do 2-4-6-8, and then connect them in parallel at the both ends).

5. Conclusion
Compared with test methods of the traditional power frequency and inductive resonance (50 Hz), technology about frequency conversion resonance applied to the test of XLPE cable has a good start, such as in-depth implementation about GB50150-2016 Standard of handover test for electrical equipment. It will have a promising application with the successful experiences which are from foreign countries and domestic experts' unified understanding

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