On-Site AC Withstand Test of 200kV XLPE Crosslinked Cable System

Shanghai Himalayal Corporation Limited, SHANGHAI, CHINA

Abstract: This article raised existing questions in current domestic XLPE crosslinked cable commissioning test, discussed feasibility of 110kV, 220kV HV power cable on-site AC withstand with variable frequency resonance instrument, demonstrated effect and feasibility of variable frequency resonance transformer in XLPE crosslinked cable on-site AC withstand with practical examples in engineering practice applying variable frequency resonance instrument.
Key words: cable, on-site, AC withstand, variable frequency resonance

1. Problem introduction

1.1 Problems and status

More and more XLPE crosslinked polyethylene insulating power cable are applied as substitute to the original oil charged butter paper insulating power cable both inland and overseas, yet due to factors of large power capacity and limited test equipments, crosslinked cable commission test continues to adopt DC withstand test method. Multiple research results from research institutes inland and overseas indicate that DC test causes damage of different degrees on XLPE crosslinked polyethylene cable. Some researches point out that XLPE structure stores accumulated unipolar residual charge adding AC voltage peak value may only cause cable breakdown. Some inland research institutes consider that during crosslinked polyethylene cable test, due to space charge effect, actual insulated electric field strength can be 11 times higher than working electric field strength. Even though crosslinked polyethylene insulating cable passes DC test without breakdown, it will cause severe damage to the insulator. Moreover, by reason that imposed DC voltage field strength distribution is different from operated AC voltage field strength distribution, DC test is incapable of simulating real overvoltage borne by cable during operation nor efficiently detect flaws on cable, cable joint and construction craft. Therefore, application of non-DC method for crosslinked cable withstand test is receiving more and more attention. Our peers overseas are currently using VLF(Very Low Frequency) power source on medium and low voltage cables for withstand test. Due to urban power network construction and rehabilitation in recent years, 110kV and above XLPE crosslinked cable or cable joint breakdown occurred occasionally. The solution to efficient commissioning test for 110kV and above XLPE crosslinked cable is becoming most concerned.

1.2 Standard problem

On account of problems on instrument capacity and volume, there is, for the time being no national standard regarding on-site AC withstand test of high voltage cable after installation, yet there've been doubts against DC withstand test standard for the reasons mentioned. DC test method is applied by CIGRI (Conference International des Grands Reseaux Electriques) 21st workgroup squadron in <High voltage cable with extruded insulation acceptance test recommendation guide>. In standard IEC60840, 45-160kV installed cable test standard added 1.7U05 minute or 1U024 hour AC test standard besides the original DC test standard, with only requirements on AC test, namely 20-300HZ1.4U0.60 minutes. In order to conduct efficient

commissioning test on installed crosslinked cable, Shanghai Himalayal Corporation recently added standard on crosslinked cable AC withstand test to the item of cable main insulating withstand test into the revised <Power equipment commissioning and preventive test procedures>.

2. Test equipment

Large capacity power cable demands large capacity test equipment during AC withstand test. For a test procedure extending 50 weeks, large capacity power cable AC withstand test is hardly possible after on-site installation. For instance, test of a 6.9km 220kV crosslinked cable requires approximately 18MVA (50Hz) of power. Current at high voltage side of the circuit amounts to about 81A. Variable frequency resonance system is currently applied internationally to high voltage cable on-site test. CIGRE 21st workgroup also recommends 30-300Hz variable frequency resonance system for on-site AC withstand test.

Beijing Power Supply Bureau recently imported a set of variable frequency resonance system and has successfully conducted on-site AC withstand test on three 220kV 17.7km XLPE crosslinked cables after commissioning and tryout.

In contrast with the traditional 50 week AC test equipment and adjustable inductance and adjustable capacitance resonance system, variable frequency resonance system is featured with high quality factor, low power required, small volume and light weight. Index as shown below:

Frequency	25-300Hz (depends on load)
Quality factor	70-120
System weight	0.5-2kg/kVA
Number of components	3
Mechanical parts	No moving parts

The variable frequency resonance system is ordered based on power cable construction of Beijing area and specific conditions of GIS equipment by Beijing Power Supply Bureau, capable of testing 0.2μf/km 220kV power cable at maximum length of 10km in accordance with 1.7U0 test standard. This system can be divided into two subsystems sharing one computer control unit. Among which main performance parameter of the testing part for power cable system is shown on table 1.

Table 1

Item	Parameter
HV rated voltage	230kV
HV rated current	83A
Frequency range	25-300Hz
Load capacity range	17μf – 2.1μf
Low voltage input voltage	400V±10%
Low voltage input phase number	Phase 3 Line 4
Low voltage input frequency	50Hz
Low voltage input power	200kVA

Variable frequency test system works obeying the series resonance circuit principle. Resonance point can be reached by adjusting frequency of frequency converter to intrinsic frequency of series resonance circuit. After circuit resonance, output voltage waveform appears pure sin wave, system frequency is determined by L-C parameter of the circuit. As shown on the formula below:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

..... (1)

In this formula, reactance value of the reactor is fixed, therefore system frequency is determined by capacity of load capacitor. Minimum resonance frequency value exists at maximum load capacitance. Frequency increases as load capacitance reduces, system load frequency curve at fixed inductance 16H as shown on figure 1.

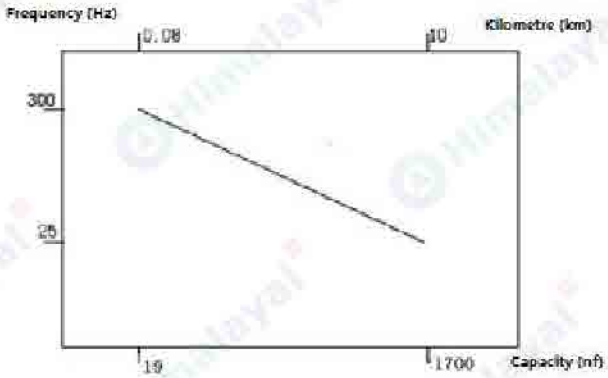

Fig.1 System load characteristic curve

3. On-site test

3.1 Test field

Fig.2 Test field layout

3.2 Test principle block diagram

On-site test principle block diagram as shown on figure 3

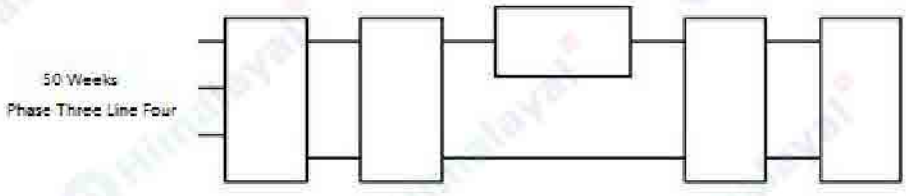

Fig.3 Test principle block diagram

Control unit on the block diagram above includes switch circuit, frequency convertor, microprocessor, feedback voltage measurement system, automatic control and feed-out system, etc. There're two main software in the control unit, including microprocessor software and PLC (Program Logic Controller) and SIMAIC software. On the principle block diagram, excitation transformer is capable of increasing output square voltage of the frequency converter to test level,

satisfying voltage requirement of reactor, load and high voltage circuit at certain quality factor. Oil-immersed high voltage reactor applied has fixed reactance. Specially designed iron core and coil guarantees high quality factor.

3.3 Test data

In Beijing area, previous commissioning test of power cable at and below 220kV generally applies DC test method. A handful of joint breakdown accidents occurred after the cables were put into operation and imposed working voltage in the year 1999. AC withstand test of multiple 220kV/110kV power cables with total length of 27km has been successfully conducted since the AC withstand test is applied to 220kV (including 110kV) cables. These instruments are currently in normal operation. Main test parameter and main test data as shown on table 2 and table 3.

Table 2

Serial Number	Route Name	Voltage level	Cross Area (mm^2)	Capacitance (C)	Length (km)	Remarks
1	Zhichunli-Xizhimen	220kV	1000	0.21μf/km	5.4	Double circuit commissioning
2	Balizhuang-Zizhuyuan	110kV	630	0.19μf/km	1.3	Commissioning
3	Xizhimen interconnecting transformer	220kV	800	0.149μf/km	0.04	Commissioning
4	Zuoanmen-Wangfujing	220kV	800	0.147μf/km	6.9	Double circuit commissioning
5	Taiyanggong-Beijisi	110kV	630	0.19μf/km	4	Double circuit commissioning

Main test parameter

Table 3

Serial Number	Route Name	U(kV)	f(Hz)	I(A)	Q	S(kVA)	I_B(A)	I_N(A)	T(Min)
1	Zhi-Xi B	177.8	39.86	43.8	184	7836	71	5.8	60
2	Zuo-Wang B	177.8	38.7	45.1	189	8.25	70.8	4.2	60
3	Ba-Zi B	108.8	80.33	13.3	177	----	----	----	5

Parameters in tables above are measured value during the test, basic calculation formula as following:

$$f = \frac{1}{2\pi\sqrt{LC}} \quad \text{..... (2)}$$

$$I = U\sqrt{\frac{C}{L}} \quad \text{..... (3)}$$

$$S = U \cdot I \quad \text{.....(4)}$$

During practical on-site operation, first step before the test is preliminary calculation with calculating software of f, I, S and power required at low voltage side based on parameters of test cable. Main aims of this practice as following:

a) Make sure parameters of test object within range of test equipment.
b) Select exciter transformer turn ratio properly.
c) Ensure proper capacity selection of low voltage power supply transformer and matched low voltage appliance via calculated capacity of low voltage power supply.

3.4 Test power source selection and control

For AC withstand test of 220kV crosslinked cable, one crucial task when working with resonance transformer is choosing low voltage power supply rationally. Capacity of low voltage test power supply required is usually large when cable route covers a long distance. Capacity required for low voltage test is much determined by quality factor value Q in the system test besides capacity of the test object. Q in the system circuit can be described as:

$$Q = \frac{S_H}{S_L} \quad \text{.....(5)}$$

In the formula:

S_H — apparent power at high voltage side of the test circuit

S_L — apparent power output of the unit controlled by the low voltage side

Which means under certain test condition, the higher the value of Q, the lower low voltage power is required. Value of Q of variable frequency resonance system is normally within range of 70-120, System designed value of Q in sub system of cable test is approximately 100. Take the two 220kV routes of Zhichunli-Zhiximen and Zuoanmen-Wangfujing as well as the 110kV route of Balizhuang-Zizhuyuan as example, this study conducted comparative calculation at various values of Q with the system calculation software. Specifications as shown on table 4:

Table 4:

Type RSE	400	400	400	400	400	400
Load capacitance（nf）	1134.0	1134.0	1014.0	1014.0	247.0	247.0
Reactor inductance（H）	16.2	16.2	16.2	16.2	16.2	16.2
Test voltage（kV）	178	178	178	178	108	108
Q factor	100	184	100	189	100	177
Transformer ratio	4.50	4.50	4.50	4.50	4.50	4.50
Mains voltage（v）	400	400	400	400	400	400
Frequency（HZ）	37.13	37.13	39.27	39.27	79.56	79.56
Test current（A）	47.09	47.09	44.53	44.53	13.34	13.34
Test power（kVA）	8383	8383	7929	7929	1440	1440
Primary current（A）	211.9	211.9	200.4	200.4	60	60
Primary power（kVA）	83.8	45.6	79.3	41.9	14.4	8.1
Phase current（A）	145.2	78.9	137.3	72.6	24.9	14.1
Inverter modulation（%）	77.7	42.2	77.7	42.1	47.1	26.6

Note: First and second data lines on the table above represent route Zhi-Xi (220kV), third and fourth data lines represent route Zuo-Wang (220kV), fifth and sixth data lines represent route

Ba-Zi (110kV.)

Capacity of test object can be acquired by cable design parameter or practical measurement during parameter calculation. Inductance is a fixed value for frequency modulation resonance system, but value of Q can only be estimated during calculation due to indefinite factors like on-site wiring. Take route Zuo-Wang in table 4 as an example, when Q equals 100, prime power is 79.3kVA, current absorbed from power supply already reaches 137.3A, a 100kVA power transformer is required as special power source for the test. However, in practical working conditions, due to satisfactory reactor performance and good voltage-sharing measures taken on the test circuit and proper wire selection, measured value of Q can reach 189, low voltage power equals only 41.9kVA, current generated from power source is 72.6A, thus one 50kVA power transformer is enough for the test. Should power of the 6.9km 800mm^2 220kV power cable in the urban power network can be controlled to meet such standard during AC withstand test, it is highly feasible with respect to on-site test power supply.

3.5 Conclusion

The following conclusions can be drawn based on discussions above and examples of practical AC withstand test on several 220kV/110kV XLPE crosslinked power cables in Beijing area:

a) Variable frequency resonance transformer is applicable and effective serving as AC test power supply for on-site AC withstand test of XLPE crosslinked power cable at voltage level of 220kV/110kV or below, this application avoids adverse impact on cable caused by DC withstand and problem of effectiveness of DC withstand test. The AC system is convenient in transportation and layout for its small volume, and is simple for on-site installation, user friendly and highly reliable.

b) There have been operational experiences in variable frequency resonance test overseas, corresponding test stipulation is included in IEC standard.

c) Based on variable frequency resonance system parameter, proper control of voltage-sharing measures and wire selection of all segments can improve Q value of the system, greatly reduce power absorbed from power source, thus improve efficiency of the entire system, adding feasibility of practical application.

d) Throughout the first practice of on-site AC withstand test on 6.9km 220kV XLPE crosslinked power cable with variable frequency resonance equipment conducted by Beijing Power Supply Bureau, this variable frequency resonance system is capable of testing 11km power cable with cable parameter 0.21μf/km in maximum in accordance with 220kV AC withstand standard 1.4U_0.

110kV/220kV XLPE crosslinked power cable will be more popularized in urban power network as domestic urban power network construction takes place. Managing on-site AC withstand commissioning test of high voltage crosslinked power cable has significant meaning to safe operation of urban power network.