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CNAS L0699



# TEST REPORT

CEPRI-EETC09-2023-0812 (E)

Client: Shandong Qixing High Voltage Electric Co., Ltd.

Object: Dry capacitive transformer bushing

Type: QXBRGW-550/4000-4

Test Category: Routine Tests /Type Tests



CHINA ELECTRIC POWER RESEARCH INSTITUTE



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中国电研

Test Report	China Electric Power Research Institute		CEPRI-EETC09-2023-0812 (E) Total 33 Page 2
Client	Shandong Qixing High Voltage Electric Co., Ltd.	Manufacturer	Shandong Qixing High Voltage Electric Co., Ltd.
Object	Dry capacitive transformer bushing	Type	QXBRGW-550/4000-4
Sampling procedure	By the Client	Serial No.	2303B001S
Test Category	Routine Tests /Type Tests	Date	2023.03.21~2023.03.31
Requirements	<p>1. GB/T 4109-2022 Insulated bushings for alternating voltages above 1000V</p> <p>2. IEC 60137:2017 Insulated bushings for alternating voltages above 1000V</p>		
Conclusion	<p>According to GB/T 4109-2022, IEC 60137:2017 routine tests and type tests were performed on QXBRGW-550/4000-4 dry capacitive transformer bushing which was provided by Shandong Qixing High Voltage Electric Co., Ltd. All the results were in accordance with the requirements.</p>		
Note	/		
Tested by: 郭文亮		刘西超	
Checked by: 肖忠明		Verified by: 刘勇	
Approved by: 叶国雄		Date of issue: 2023-05-09	



## Test Results

No.	Item	Requirements	Results	Evaluation
<b>Routine Tests</b>				
1	Measurement of dielectric dissipation factor( $\tan \delta$ ) and capacitance at ambient temperature	The measured $\tan \delta$ at the test voltage of 10kV, $1.05U_m/\sqrt{3}$ and $U_m$ shall not exceed 0.4%. $\Delta \tan \delta$ shall not exceed 0.1% when the power frequency voltage increases from $1.05U_m/\sqrt{3}$ to $U_m$ .	10kV $\tan \delta$ : 0.320% Cx: 733.3pF 333kV $\tan \delta$ : 0.336% Cx: 733.8pF 550kV $\tan \delta$ : 0.341% Cx: 733.9pF	Pass
2	Dry lightning impulse voltage withstand test	105% rated lightning impulse: 1759kV/-3 Waveform: 1.2/50 $\mu$ s Rated chopped impulse(115% rated lightning impulse): 1926kV/-2 Chopped time: (2~6) $\mu$ s No flashover or puncture occurs.	Lightning impulse: 1681kV~1747kV -3 Chopped impulse: 1912kV、1928kV -2 No flashover or puncture occurred.	Pass
3	Dry power-frequency voltage withstand test	The withstand voltage of 750kV is applied for 60s between the high voltage terminal of bushing and earth. No flashover or puncture occurs.	750kV/50Hz/60s No flashover or puncture occurred.	Pass
4	Measurement of partial discharge quantity	Pre-stress voltage: 750kV/60s Test voltage: 550kV Permissible PD level: 10pC Test voltage: 476kV Permissible PD level: 10pC Test voltage: 333kV Permissible PD level: 5pC	Pre-stress voltage: 750kV/60s Test voltage: 550kV PD level: 7pC Test voltage: 476kV PD level: 5pC Test voltage: 333kV PD level: 4pC	Pass
5	Measurement of dielectric dissipation factor( $\tan \delta$ ) and capacitance at ambient temperature	The measured $\tan \delta$ at the test voltage of 10kV, $1.05U_m/\sqrt{3}$ and $U_m$ shall not exceed 0.4%. $\Delta \tan \delta$ shall not exceed 0.1% when the power frequency voltage increases from $1.05U_m/\sqrt{3}$ to $U_m$ .	10kV $\tan \delta$ : 0.327% Cx: 733.3pF 333kV $\tan \delta$ : 0.339% Cx: 733.7pF 550kV $\tan \delta$ : 0.347% Cx: 733.7pF	Pass



No.	Item	Requirements	Results	Evaluation
6	Tests of tap insulation	The withstand voltage of 2kV is applied for 60s between the test tap and earth. Before and after the voltage withstand test, $\tan \delta$ and capacitance with respect to earth shall be measured, $C_x \leq 10000$ pF, $\tan \delta \leq 5\%$ .	Test tap: 2kV/50Hz/60s No flashover or puncture occurred. Before the voltage withstand test 1kV $\tan \delta$ : 0.560% Cx: 1111.5pF After the voltage withstand test 1kV $\tan \delta$ : 0.577% Cx: 1112.2pF	Pass
<b>Type Tests</b>				
7	Dry lightning impulse voltage withstand test	100% rated lightning impulse: 1675kV/+15 Waveform: 1.2/50 $\mu$ s Rated chopped impulse(121% rated lightning impulse): 2027kV/-5 Chopped time: (2~6) $\mu$ s 110% rated lightning impulse: 1843kV/-15 No flashover or puncture occurs.	Lightning impulse: 1662kV~1678kV +15 1826kV~1848kV -15 Chopped impulse: 1978kV~2008kV -5 No flashover or puncture occurred. Atmosphere correction factor $K_t=1.003$	Pass
8	Dry or wet switching impulse voltage withstand test	Under dry condition 110% rated switching impulse: 1430kV/-15 Waveform: 250/2500 $\mu$ s No flashover or puncture occurs.	Switching impulse voltage 1392kV~1400kV -15 No flashover or puncture occurred. Atmosphere correction factor $K_t=1.000$	Pass
		Under wet condition 100% rated switching impulse: 1300kV/ $\pm 15$ Waveform: 250/2500 $\mu$ s No flashover or puncture occurs.	Switching impulse voltage 1281kV~1306kV +15 1286kV~1305kV -15 No flashover or breakdown occurred. Water conductivity:96 $\mu$ S/cm Horizontal precipitation:1.4mm/min Vertical precipitation:1.5mm/min Atmosphere correction factor $K_t=1.008$	Pass



No.	Item	Requirements	Results	Evaluation
9	Long duration power-frequency voltage withstand test	<p>The bushing shall be subjected to the voltage of <math>1.1 U_m / \sqrt{3}</math> for 5min;            Raise to the voltage of <math>1.5 U_m / \sqrt{3}</math> for 5min;            Raise to the voltage of <math>U_m</math> for 1min;            Reduce to the voltage of <math>1.5 U_m / \sqrt{3}</math> for 60min;            Reduce the voltage of <math>1.1 U_m / \sqrt{3}</math> for 5min.            Partial discharge shall be monitored during the whole application of test voltage and shall be recorded at 5min intervals.</p>	<p>349kV/50Hz/5min            476kV/50Hz/5min            550kV/50Hz/1min            476kV/50Hz/60min            349kV/50Hz/5min            No flashover or puncture occurred.            Details are shown in content 9.</p>	Pass
10	Measurement of dielectric dissipation factor ( $\tan \delta$ ) and capacitance at ambient temperature	<p>The measured <math>\tan \delta</math> at the test voltage of 10kV, <math>1.05 U_m / \sqrt{3}</math> and <math>U_m</math> shall not exceed 0.4%.  <math>\Delta \tan \delta</math> shall not exceed 0.1% when the power frequency voltage increases from <math>1.05 U_m / \sqrt{3}</math> to <math>U_m</math>.</p>	<p>10kV <math>\tan \delta</math>: 0.331%            Cx: 733.5pF            333kV <math>\tan \delta</math>: 0.347%            Cx: 733.6pF            550kV <math>\tan \delta</math>: 0.349%            Cx: 733.7pF</p>	Pass
11	Thermal stability test	<p>The temperature of the oil shall be maintained at <math>(90 \pm 2)^\circ\text{C}</math>. After the oil and the bushing has reached thermal equilibrium, measuring dielectric dissipation factor (<math>\tan \delta</math>) frequently and recording ambient temperature at each measurement.            The bushing has reached thermal stability when its dielectric dissipation factor rises no more than 0.02% over a period of 5 h.            The bushing shall be considered to have passed the test if it reaches thermal stability and subsequently withstands dielectric routine tests without significant change from previous results.</p>	Details are shown in content 11.	Pass



No.	Item	Requirements	Results	Evaluation
12	Electromagnetic Compatibility (EMC) test	<p>A voltage of <math>1.1 U_m / \sqrt{3}</math> shall be applied between the high voltage terminal of bushing and earth, and maintained for at least 5 min.</p> <p>After that, the voltage shall be decreased by steps down to <math>0.3 U_m / \sqrt{3}</math>, then raised again by steps to the initial value and finally decreased by steps to <math>0.3 U_m / \sqrt{3}</math>. The voltage regulation amplitude is <math>0.1 U_m / \sqrt{3}</math>.</p> <p>The radio interference voltage shall not exceed <math>500 \mu V</math> at <math>1.1 U_m / \sqrt{3}</math>.</p>	Details are shown in content 12.	Pass
13	Temperature rise test	<p>The test shall be carried out at <math>I_r (1 \pm 2\%)</math> at rated frequency. The test shall be continued until the temperature rise is sensibly constant, the limits of temperature rises and temperature limits are shown as follows:</p> <p>Current carrying and non-current carrying metal parts in contact with insulation : 90K/120°C</p> <p>Terminals to be connected to exterior conductors by screws or bolts: 75K/105°C</p>	Details are shown in content 13.	Pass
14	Verification of thermal short-time current withstand	The bushing shall be considered to be able to withstand the standard value of $I_{th}$ if $\theta_f$ does not exceed 180°C.	The calculated final temperature of the conductor( $\theta_f$ ): 120°C	Pass
15	Cantilever load withstand test	The load shall be applied perpendicular to the axis of the bushing at the mid-point of the air side terminal for 60s. No evidence of damage (deformation, rupture or leakage) shall be detected, and it shall withstand a repetition of all routine tests without significant change from previous results.	<p>Test load: 5000N</p> <p>Duration: 1 min</p> <p>No evidence of damage (deformation, rupture or leakage).</p>	Pass



No.	Item	Requirements	Results	Evaluation
16	Verification of dimensions	The dimensions of the bushing under test shall be in accordance with the relevant drawings, particularly with regard to any dimensions to which special tolerances apply and to details affecting interchangeability.	Creepage distance(Air side/Oil side): 20880/1430mm Arcing distance (Air side/Oil side): 4710/1410mm Total length: 7680mm The dimensions of the bushing were in accordance with the relevant drawings.	Pass
<b>Routine Tests</b>				
17	Measurement of dielectric dissipation factor( $\tan\delta$ ) and capacitance at ambient temperature	The measured $\tan\delta$ at the test voltage of 10kV, $1.05U_m/\sqrt{3}$ and $U_m$ shall not exceed 0.4%. $\Delta\tan\delta$ shall not exceed 0.1% when the power frequency voltage increases from $1.05U_m/\sqrt{3}$ to $U_m$ .	10kV $\tan\delta$ : 0.321% Cx: 732.6pF 333kV $\tan\delta$ : 0.331% Cx: 732.6pF 550kV $\tan\delta$ : 0.339% Cx: 732.7pF	Pass
18	Dry lightning impulse voltage withstand test	105% rated lightning impulse: 1759kV/-3 Waveform: 1.2/50 $\mu$ s Rated chopped impulse(115% rated lightning impulse) : 1926kV/-2 Chopped time: (2~6) $\mu$ s No flashover or puncture occurs.	Lightning impulse: 1750kV~1771kV -3 Chopped impulse: 1919kV、1920kV -2 No flashover or puncture occurred.	Pass
19	Dry power-frequency voltage withstand test	The withstand voltage of 750kV is applied for 60s between the high voltage terminal of bushing and earth. No flashover or puncture occurs.	750kV/50Hz /60s No flashover or puncture occurred.	Pass



No.	Item	Requirements	Results	Evaluation
20	Measurement of partial discharge quantity	Pre-stress voltage: 750kV/60s Test voltage: 550kV Permissible PD level: 10pC Test voltage: 476kV Permissible PD level: 10pC Test voltage: 333kV Permissible PD level: 5pC	Pre-stress voltage: 750kV/60s Test voltage: 550kV PD level: 4pC Test voltage: 476kV PD level: 3pC Test voltage: 333kV PD level: 3pC	Pass
21	Measurement of dielectric dissipation factor( $\tan \delta$ ) and capacitance at ambient temperature	The measured $\tan \delta$ at the test voltage of 10kV, $1.05U_m/\sqrt{3}$ and $U_m$ shall not exceed 0.4%. $\Delta \tan \delta$ shall not exceed 0.1% when the power frequency voltage increases from $1.05U_m/\sqrt{3}$ to $U_m$ .	10kV $\tan \delta$ : 0.325% Cx: 732.8pF 333kV $\tan \delta$ : 0.337% Cx: 732.9pF 550kV $\tan \delta$ : 0.342% Cx: 732.9pF	Pass
22	Tests of tap insulation	The withstand voltage of 2kV is applied for 60s between the test tap and earth. Before and after the voltage withstand test, $\tan \delta$ and capacitance with respect to earth shall be measured, $C_x \leq 10000$ pF, $\tan \delta \leq 5\%$ .	Test tap: 2kV/50Hz/72s No flashover or puncture occurred. Before the voltage withstand test 1kV $\tan \delta$ : 0.578% Cx: 1112.3pF After the voltage withstand test 1kV $\tan \delta$ : 0.587% Cx: 1112.5pF	Pass
23	Tightness test at the flange or other fixing device	For liquid-immersed bushings, the tank shall be filled with air or any suitable gas at a relative pressure of $0.15\text{MPa} \pm 0.01\text{MPa}$ and maintained for 15min, or oil at a relative pressure of $0.1\text{MPa} \pm 0.01\text{MPa}$ and maintained for 12h, there shall be no leakage.	Test pressure: 0.15MPa (SF <sub>6</sub> ) Duration: 15 min No evidence of leakage.	Pass



No.	Item	Requirements	Results	Evaluation
24	Visual inspection and dimensional check	No surface defects shall be tolerated which could affect the satisfactory performance in service. Dimensions of parts for assembling and/or interconnection shall be in accordance with the relevant drawings, checked by sampling.	Meet the requirements.	Pass

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## Content

1. Measurement of dielectric dissipation factor ( $\tan\delta$ ) and capacitance at ambient temperature

## 1.1 Reference standard requirement

The measured  $\tan\delta$  at the test voltage of 10kV,  $1.05U_m/\sqrt{3}$  and  $U_m$  shall not exceed 0.4%.

$\Delta\tan\delta$  shall not exceed 0.1% when the power frequency voltage increases from  $1.05U_m/\sqrt{3}$  to  $U_m$ .

## 1.2 Data

Ambient temperature:16°C

Relative humidity:63%

Modality of application	Test voltage(kV)	$\tan\delta$ (%)	$C_x$ (pF)
Between high voltage terminal and test tap	10	0.320	733.3
	333	0.336	733.8
	550	0.341	733.9

## 1.3 Test result

The test object passed the tests.

## 2. Dry lightning impulse voltage withstand test

## 2.1 Reference standard requirement

The test object shall be subject to 3 full lightning impulses of negative polarity at 1759kV (peak value).  
2 chopped lightning impulses of negative polarity at 1926kV (peak value).

No disruptive discharge on non-self restoring insulation shall occur and no evidence of insulation failure shall be detected.

## 2.2 Data

Ambient temperature: 16°C

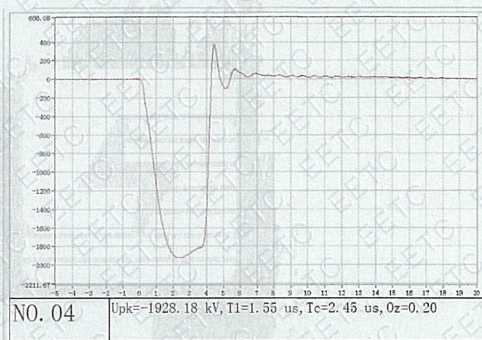
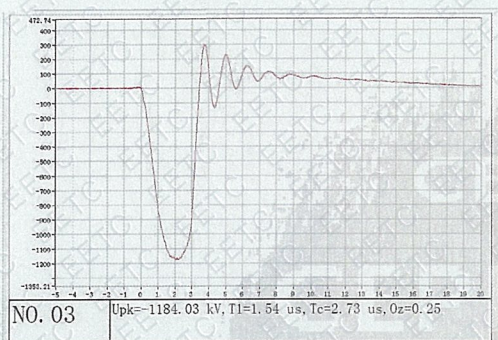
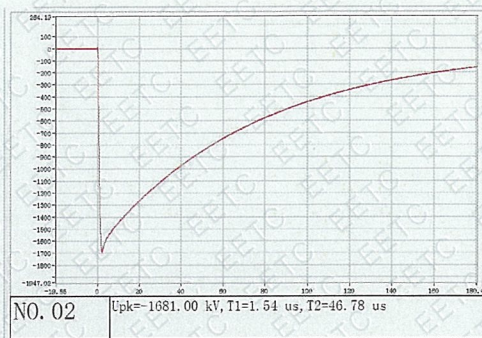
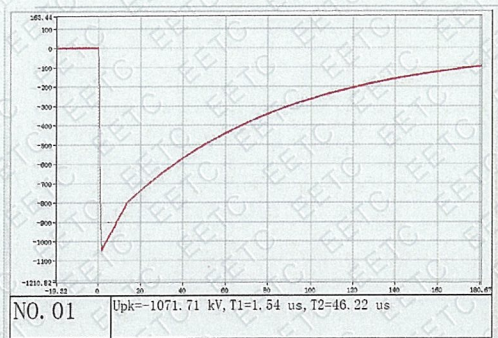
Relative humidity: 63%

Ambient air pressure: 101.8kPa

No.	Voltage polarity	Test voltage (peak) (kV)	Chopped time ( $\mu$ s)	Waveform No.	Result
1	Negative lightning impulse	1072	/	1	Pass
2	Negative lightning impulse	1681	/	2	Pass
3	Negative chopped impulse	1184	2.7	3	Pass
4	Negative chopped impulse	1928	2.5	4	Pass
5	Negative chopped impulse	1912	2.4	5	Pass
6	Negative lightning impulse	1741	/	6	Pass
7	Negative lightning impulse	1747	/	7	Pass



Classical test waveforms:



2.3 Test result

The test object passed the tests.

3. Dry power-frequency voltage withstand test

3.1 Reference standard requirement

The withstand voltage of 750kV is applied for 60s between the high voltage terminal of bushing and earth. No flashover or puncture occurs.

3.2 Data

Ambient temperature:16°C      Relative humidity:63%      Ambient air pressure: 101.3kPa

Modality of application	Test voltage/Frequency/Duration
Between high voltage terminal and earth	750kV/50Hz/60s

3.3 Test result

The test object passed the tests.



**4. Measurement of partial discharge quantity****4.1 Reference standard requirement**

Pre-stress voltage: 750kV/60s      Test frequency: 50Hz

Test voltage: 550kV      Permissible PD level: 10pC

Test voltage: 476kV      Permissible PD level: 10pC

Test voltage: 333kV      Permissible PD level: 5pC

**4.2 Data**

Ambient temperature: 16°C

Relative humidity: 63%

Pre-stress voltage (kV)	750		
Test voltage (kV)	550	476	333
PD level (pC)	7	5	4

**4.3 Test result**

The test object passed the tests.

**5. Measurement of dielectric dissipation factor ( $\tan\delta$ ) and capacitance at ambient temperature****5.1 Reference standard requirement**The measured  $\tan\delta$  at the test voltage of 10kV,  $1.05U_m/\sqrt{3}$  and  $U_m$  shall not exceed 0.4%. $\Delta\tan\delta$  shall not exceed 0.1% when the power frequency voltage increases from  $1.05U_m/\sqrt{3}$  to  $U_m$ .**5.2 Data**

Ambient temperature: 16°C

Relative humidity: 63%

Modality of application	Test voltage(kV)	$\tan\delta$ (%)	$C_x$ (pF)
Between high voltage terminal and test tap	10	0.327	733.3
	333	0.339	733.7
	550	0.347	733.7

**5.3 Test result**

The test object passed the tests.



## 6. Tests of tap insulation

### 6.1 Reference standard requirement

The withstand voltage of 2kV shall be applied for 60s between the test tap and earth. No flashover or puncture occurs.

Before and after the voltage withstand test,  $\tan\delta$  and capacitance with respect to earth shall be measured,  $C_x \leq 10000$  pF,  $\tan\delta \leq 5\%$ .

### 6.2 Data

Ambient temperature: 16°C

Relative humidity: 63%

Test voltage(kV)	Duration(s)	$\tan\delta$ (%)	$C_x$ (pF)
1	/	0.560	1111.5
2	60	Voltage withstand test between test tap and earth, no flashover or puncture occurred.	
1	/	0.577	1112.2

### 6.3 Test result

The test object passed the tests.

## 7. Dry lightning impulse voltage withstand test

### 7.1 Reference standard requirement

The bushing shall be subjected to 15 full lightning impulses of positive polarity at 1675kV (peak value).

The bushing shall be subjected to 15 full lightning impulses of negative polarity at 1843kV (peak value).

The bushing shall be subjected to 5 chopped lightning impulses of negative polarity at 2027kV (peak value).

The bushing shall be considered to have passed the test if not more than two flashovers in air at positive polarity and no flashover in air at negative polarity.

### 7.2 Data

Ambient temperature: 16°C

Relative humidity: 67%

Ambient air pressure: 102.0kPa

Atmosphere correction factor:  $K_t=1.003$

No.	Voltage polarity	Test voltage (peak) (kV)	Chopped time ( $\mu$ s)	Waveform No.	Result
1	Positive lightning impulse	1144	/	1	Pass
2	Positive lightning impulse	1662	/	2	Pass
3	Positive lightning impulse	1675	/	3	Pass
4	Positive lightning impulse	1677	/	4	Pass

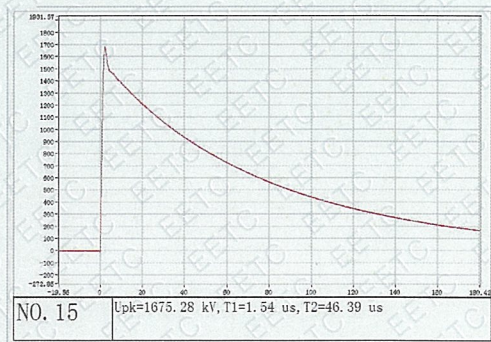
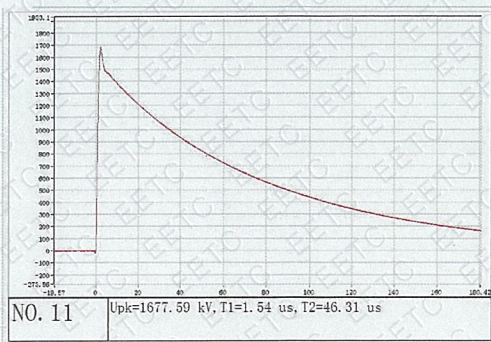
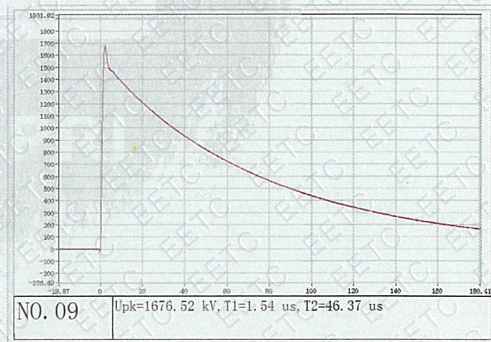
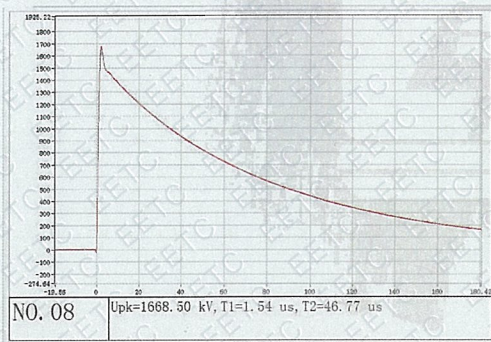
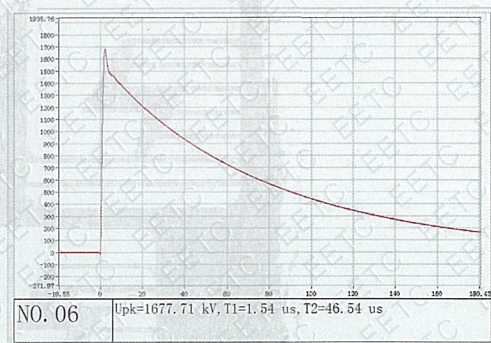
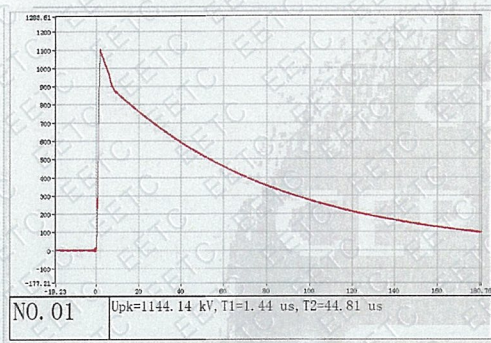


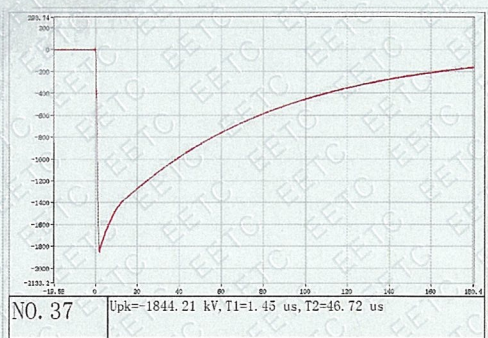
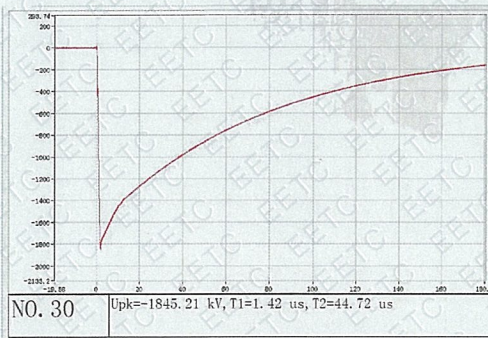
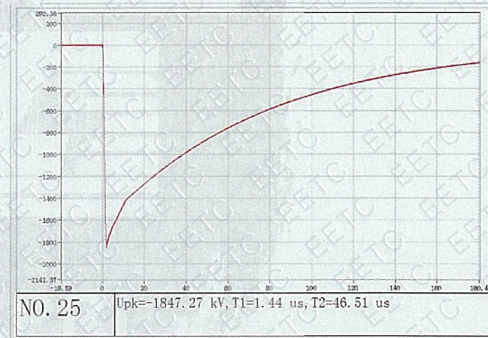
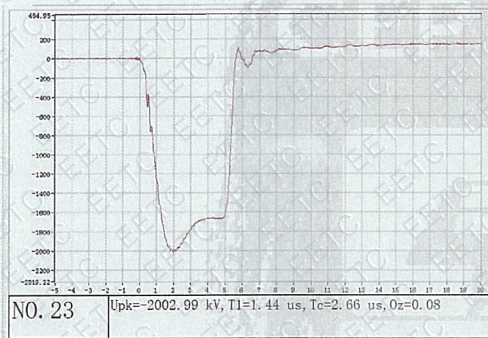
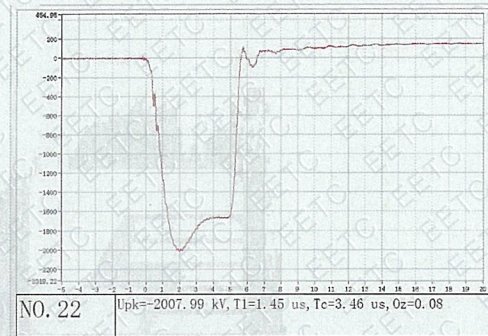
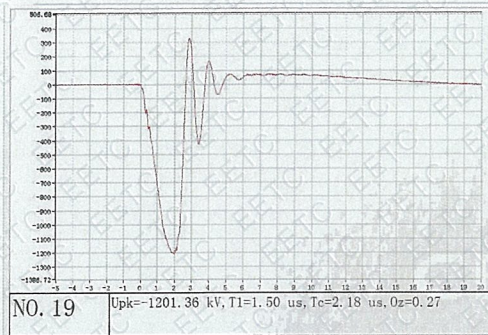
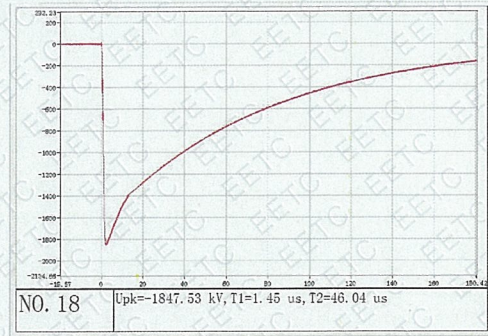
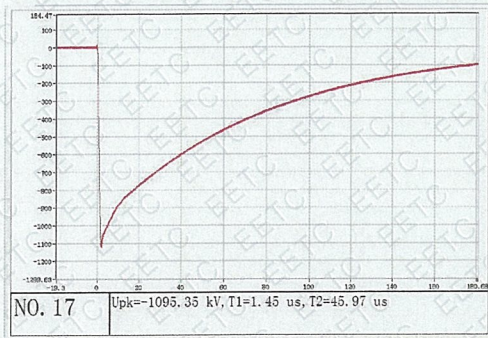
No.	Voltage polarity	Test voltage (peak) (kV)	Chopped time ( $\mu$ s)	Waveform No.	Result
5	Positive lightning impulse	1668	/	5	Pass
6	Positive lightning impulse	1678	/	6	Pass
7	Positive lightning impulse	1675	/	7	Pass
8	Positive lightning impulse	1669	/	8	Pass
9	Positive lightning impulse	1677	/	9	Pass
10	Positive lightning impulse	1673	/	10	Pass
11	Positive lightning impulse	1678	/	11	Pass
12	Positive lightning impulse	1669	/	12	Pass
13	Positive lightning impulse	1674	/	13	Pass
14	Positive lightning impulse	1666	/	14	Pass
15	Positive lightning impulse	1675	/	15	Pass
16	Positive lightning impulse	1673	/	16	Pass
17	Negative lightning impulse	1095	/	17	Pass
18	Negative lightning impulse	1848	/	18	Pass
19	Negative chopped impulse	1201	2.3	19	Pass
20	Negative chopped impulse	1978	2.3	20	Pass
21	Negative chopped impulse	1993	4.4	21	Pass
22	Negative chopped impulse	2008	3.5	22	Pass
23	Negative chopped impulse	2003	2.7	23	Pass
24	Negative chopped impulse	1982	2.7	24	Pass
25	Negative lightning impulse	1847	/	25	Pass
26	Negative lightning impulse	1841	/	26	Pass
27	Negative lightning impulse	1841	/	27	Pass
28	Negative lightning impulse	1835	/	28	Pass
29	Negative lightning impulse	1838	/	29	Pass
30	Negative lightning impulse	1845	/	30	Pass
31	Negative lightning impulse	1839	/	31	Pass
32	Negative lightning impulse	1838	/	32	Pass
33	Negative lightning impulse	1826	/	33	Pass



No.	Voltage polarity	Test voltage (peak) (kV)	Chopped time ( $\mu$ s)	Waveform No.	Result
34	Negative lightning impulse	1836	/	34	Pass
35	Negative lightning impulse	1832	/	35	Pass
36	Negative lightning impulse	1834	/	36	Pass
37	Negative lightning impulse	1844	/	37	Pass
38	Negative lightning impulse	1841	/	38	Pass

Classical test waveforms:





### 7.3 Test result

The test object passed the tests.



**8. Dry or wet switching impulse voltage withstand test****8.1 Reference standard requirement**

Under dry condition, the bushing shall be subjected to 15 switching impulses of negative polarity at 1430kV (peak value).

Under wet condition, the bushing shall be subjected to 15 switching impulses of positive and negative polarity respectively at 1300kV.

No puncture occurs at either polarity and the number of flashovers in air at polarity does not exceed two in the series of 15 impulses.

**8.2 Data**

Under dry condition

Ambient temperature:18°C

Relative humidity:35%

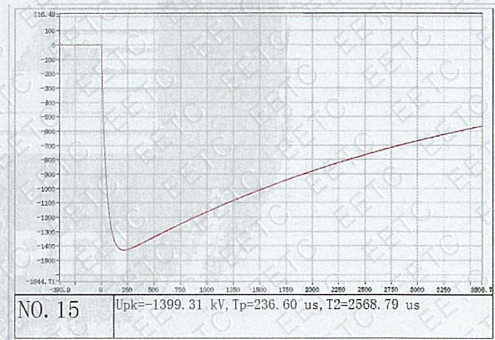
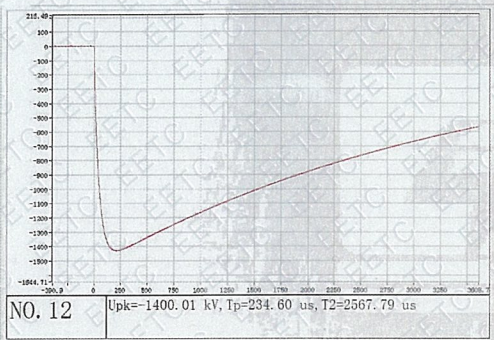
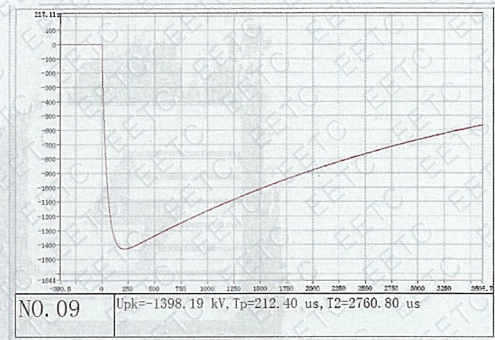
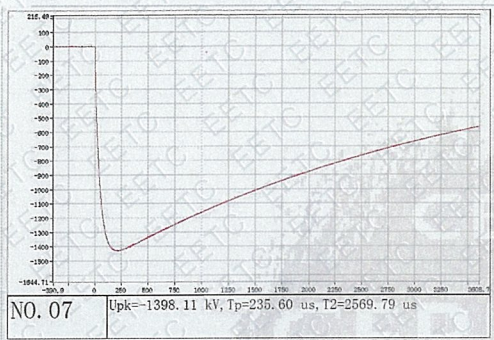
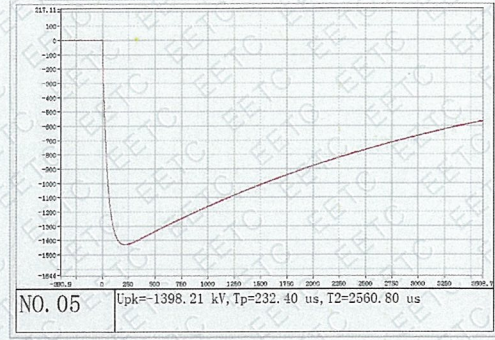
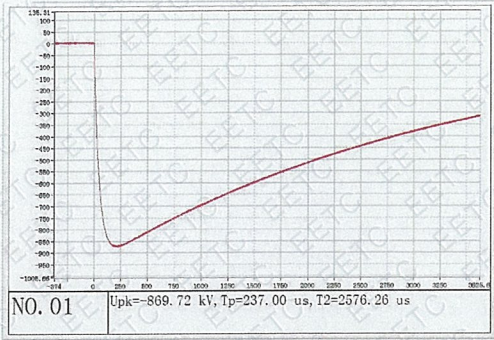
Ambient air pressure: 101.4kPa

Atmosphere correction factor:  $K_t=1.000$

No.	Voltage polarity	Test voltage (peak) (kV)	Waveform No.	Result
1	Negative lightning impulse	870	1	Pass
2	Negative lightning impulse	1392	2	Pass
3	Negative lightning impulse	1395	3	Pass
4	Negative polarity switching impulse	1394	4	Pass
5	Negative polarity switching impulse	1398	5	Pass
6	Negative polarity switching impulse	1395	6	Pass
7	Negative polarity switching impulse	1398	7	Pass
8	Negative polarity switching impulse	1395	8	Pass
9	Negative polarity switching impulse	1398	9	Pass
10	Negative polarity switching impulse	1396	10	Pass
11	Negative polarity switching impulse	1391	11	Pass
12	Negative polarity switching impulse	1400	12	Pass
13	Negative polarity switching impulse	1395	13	Pass
14	Negative polarity switching impulse	1392	14	Pass
15	Negative polarity switching impulse	1399	15	Pass
16	Negative polarity switching impulse	1395	16	Pass



Classical test waveforms:



Under wet condition

Ambient temperature:18℃

Relative humidity:35%

Ambient air pressure:101.4kPa

Atmosphere correction factor:  $K_T=1.008$

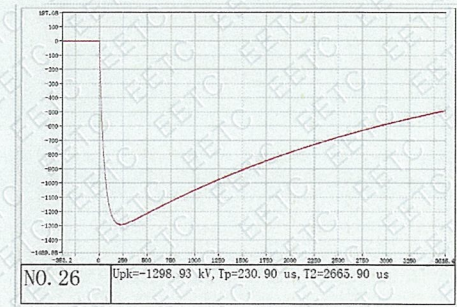
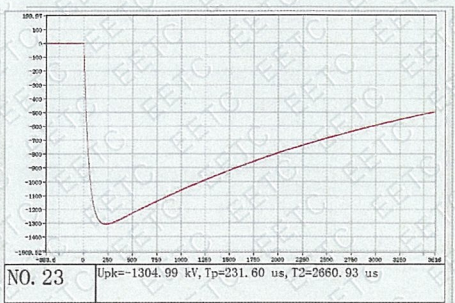
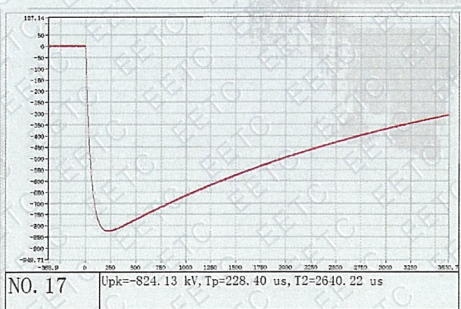
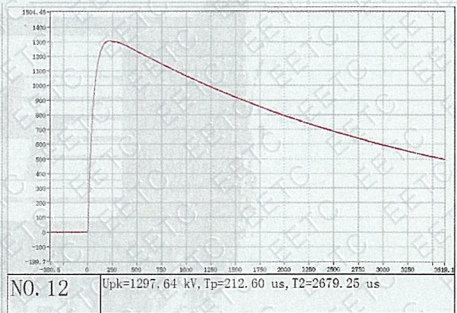
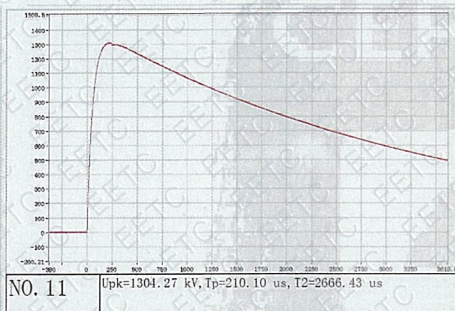
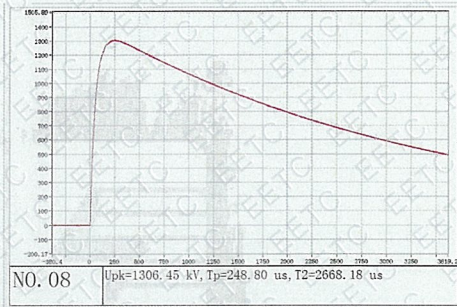
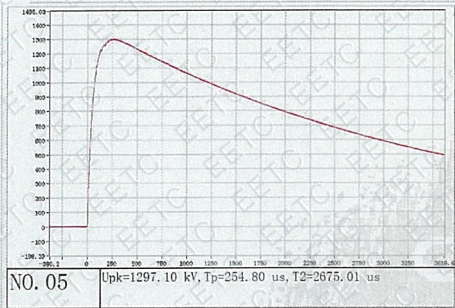
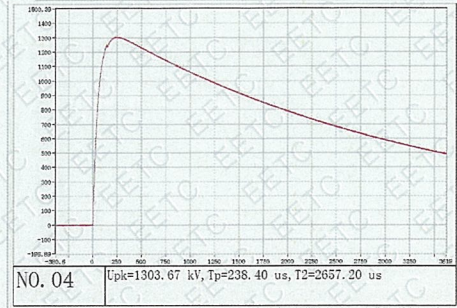
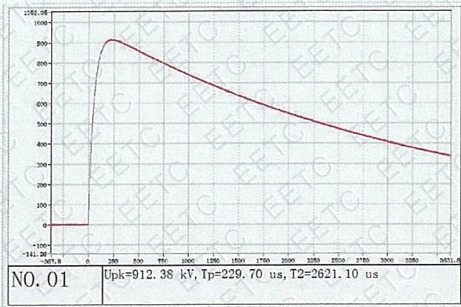
No.	Voltage polarity	Test voltage (peak) (kV)	Waveform No.	Result
1	Positive lightning impulse	912	1	Pass
2	Positive lightning impulse	1281	2	Pass
3	Positive lightning impulse	1306	3	Pass
4	Positive switching impulse	1304	4	Pass
5	Positive switching impulse	1297	5	Pass
6	Positive switching impulse	1297	6	Pass



No.	Voltage polarity	Test voltage (peak) (kV)	Waveform No.	Result
7	Positive switching impulse	1303	7	Pass
8	Positive switching impulse	1285	8	Pass
9	Positive switching impulse	1293	9	Pass
10	Positive switching impulse	1298	10	Pass
11	Positive switching impulse	1304	11	Pass
12	Positive switching impulse	1298	12	Pass
13	Positive switching impulse	1286	13	Pass
14	Positive switching impulse	1300	14	Pass
15	Positive switching impulse	1304	15	Pass
16	Positive switching impulse	1301	16	Pass
17	Negative polarity switching impulse	824	17	Pass
18	Negative polarity switching impulse	1286	18	Pass
19	Negative polarity switching impulse	1302	19	Pass
20	Negative polarity switching impulse	1301	20	Pass
21	Negative polarity switching impulse	1299	21	Pass
22	Negative polarity switching impulse	1298	22	Pass
23	Negative polarity switching impulse	1305	23	Pass
24	Negative polarity switching impulse	1301	24	Pass
25	Negative polarity switching impulse	1300	25	Pass
26	Negative polarity switching impulse	1299	26	Pass
27	Negative polarity switching impulse	1301	27	Pass
28	Negative polarity switching impulse	1287	28	Pass
29	Negative polarity switching impulse	1287	29	Pass
30	Negative polarity switching impulse	1295	30	Pass
31	Negative polarity switching impulse	1301	31	Pass
32	Negative polarity switching impulse	1303	32	Pass

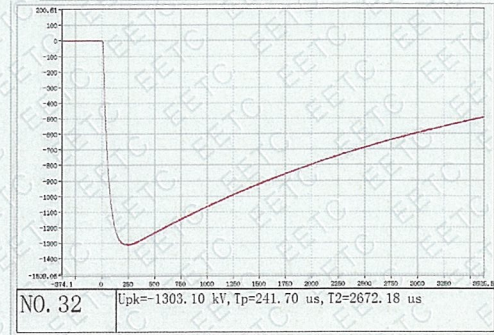
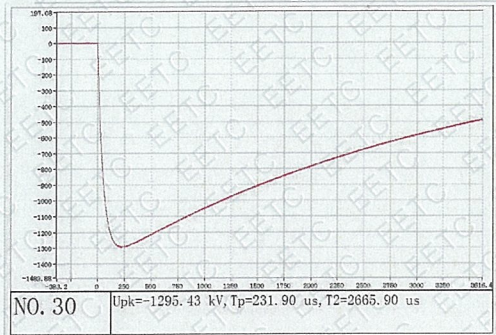


Classical test waveforms:



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国家电网公司





**8.3 Test result**

The test object passed the tests.

**9. Long duration power-frequency voltage withstand tests**

**9.1 Reference standard requirement**

- The bushing shall be subjected to the voltage of  $1.1 U_m / \sqrt{3}$  and held for a duration of 5 min;
- Raise to the voltage of  $1.5 U_m / \sqrt{3}$  and held for a duration of 5 min;
- Raise to the voltage of  $U_m$  and held for a duration of 1 min;
- Reduce to the voltage of  $1.5 U_m / \sqrt{3}$  and held for a duration of 60min;
- Reduce to the voltage of  $1.1 U_m / \sqrt{3}$  and held for a duration of 5 min.

Partial discharge shall be monitored during the whole application of test voltage and shall be recorded at 5min intervals.

**9.2 Data**

Ambient temperature: 18°C      Relative humidity: 35%

Test voltage (kV)	Time intervals (min)	PD level (pC)	Maximum permissible PD level (pC)
349	5	3	5
476	5	3	10
550	1	4	10
476	0~5	3	10
	6~10	3	
	11~15	3	
	16~20	4	
	21~25	3	
	26~30	3	
	31~35	3	
	36~40	3	
	41~45	3	
	46~50	3	
	51~55	3	
	56~60	3	
349	5	3	5

**9.3 Test result**

The test object passed the tests.



**10. Measurement of dielectric dissipation factor ( $\tan\delta$ ) and capacitance at ambient temperature****10.1 Reference standard requirement**

The measured  $\tan\delta$  at the test voltage of 10kV,  $1.05U_m/\sqrt{3}$  and  $U_m$  shall not exceed 0.4%.

$\Delta\tan\delta$  shall not exceed 0.1% when the power frequency voltage increases from  $1.05U_m/\sqrt{3}$  to  $U_m$ .

**10.2 Data**

Ambient temperature:18°C

Relative humidity:35%

Modality of application	Test voltage(kV)	$\tan\delta$ (%)	$C_x$ (pF)
Between high voltage terminal and test tap	10	0.331	733.5
	333	0.347	733.6
	550	0.349	733.7

**10.3 Test result**

The test object passed the tests.

**11. Thermal stability test****11.1 Reference standard requirement**

The temperature of the oil shall be maintained at  $(90\pm 2)^\circ\text{C}$ . After the oil and the bushing has reached thermal equilibrium, measuring dielectric dissipation factor ( $\tan\delta$ ) frequently and recording ambient temperature at each measurement.

The bushing has reached thermal stability when its dielectric dissipation factor rises no more than 0.02% over a period of 5h. The bushing shall be considered to have passed the test if it reaches thermal stability and subsequently withstands dielectric routine tests without significant change from previous results.

**11.2 Data**

Ambient temperature:18°C

Relative humidity:35%

Time	Voltage (kV)	Capacitance (pF)	$\tan\delta$ (%)	Ambient temperature (°C)	Oil temperature (°C)
16:00	440	747.3	0.269	17	89
16:30		747.3	0.269	17	90
17:00		747.4	0.268	18	89
18:30		747.4	0.268	18	90
18:00		747.4	0.267	18	90
18:30		747.4	0.267	18	90
19:00		747.4	0.267	18	90
19:30		747.4	0.267	18	90
20:00		747.4	0.267	18	90
20:30		747.4	0.266	18	90

**11.3 Test result**

The test object passed the tests.



**12. Electromagnetic Compatibility (EMC) test****12.1 Reference standard requirement**

A voltage of  $1.1 U_m/\sqrt{3}$  shall be applied between the high voltage terminal of bushing and earth, and maintained for at least 5 min. After that, the voltage shall be decreased by steps down to  $0.3 U_m/\sqrt{3}$ , then raised again by steps to the initial value and finally decreased by steps to  $0.3 U_m/\sqrt{3}$ . The voltage regulation amplitude is  $0.1 U_m/\sqrt{3}$ . The radio interference voltage shall not exceed  $500\mu\text{V}$  at  $1.1 U_m/\sqrt{3}$ .

**12.2 Data**

Ambient temperature: 17℃

Relative humidity: 35 %

Test voltage (kV)		Test frequency (MHz)	Radio interference level ( $\mu\text{V}$ )	Standard limits ( $\mu\text{V}$ )
$1.1 U_m/\sqrt{3}$	349/5min	1.0	131	/
$1.0 U_m/\sqrt{3}$	318		125	
$0.9 U_m/\sqrt{3}$	286		117	
$0.8 U_m/\sqrt{3}$	254		103	
$0.7 U_m/\sqrt{3}$	223		101	
$0.6 U_m/\sqrt{3}$	191		97	
$0.5 U_m/\sqrt{3}$	159		78	
$0.4 U_m/\sqrt{3}$	127		77	
$0.3 U_m/\sqrt{3}$	95		72	
$0.4 U_m/\sqrt{3}$	127		78	
$0.5 U_m/\sqrt{3}$	159		81	
$0.6 U_m/\sqrt{3}$	191		89	
$0.7 U_m/\sqrt{3}$	223		98	
$0.8 U_m/\sqrt{3}$	254		105	
$0.9 U_m/\sqrt{3}$	286		118	
$1.0 U_m/\sqrt{3}$	318		127	
$1.1 U_m/\sqrt{3}$	349		132	<500
$1.0 U_m/\sqrt{3}$	318		125	/
$0.9 U_m/\sqrt{3}$	286		115	
$0.8 U_m/\sqrt{3}$	254		103	
$0.7 U_m/\sqrt{3}$	223		97	
$0.6 U_m/\sqrt{3}$	191		96	
$0.5 U_m/\sqrt{3}$	159		79	
$0.4 U_m/\sqrt{3}$	127		78	
$0.3 U_m/\sqrt{3}$	95		77	

**12.3 Test result**

The test object passed the tests.



**13. Temperature rise test****13.1 Reference standard requirement**

The test shall be carried out at  $I_r$  ( $1\pm 2\%$ ) at rated frequency. The test shall be continued until the temperature rise is sensibly constant, the limits of temperature rises and temperature limits are shown as follows:

Terminals to be connected to exterior conductors by screws or bolts: 90K/120°C

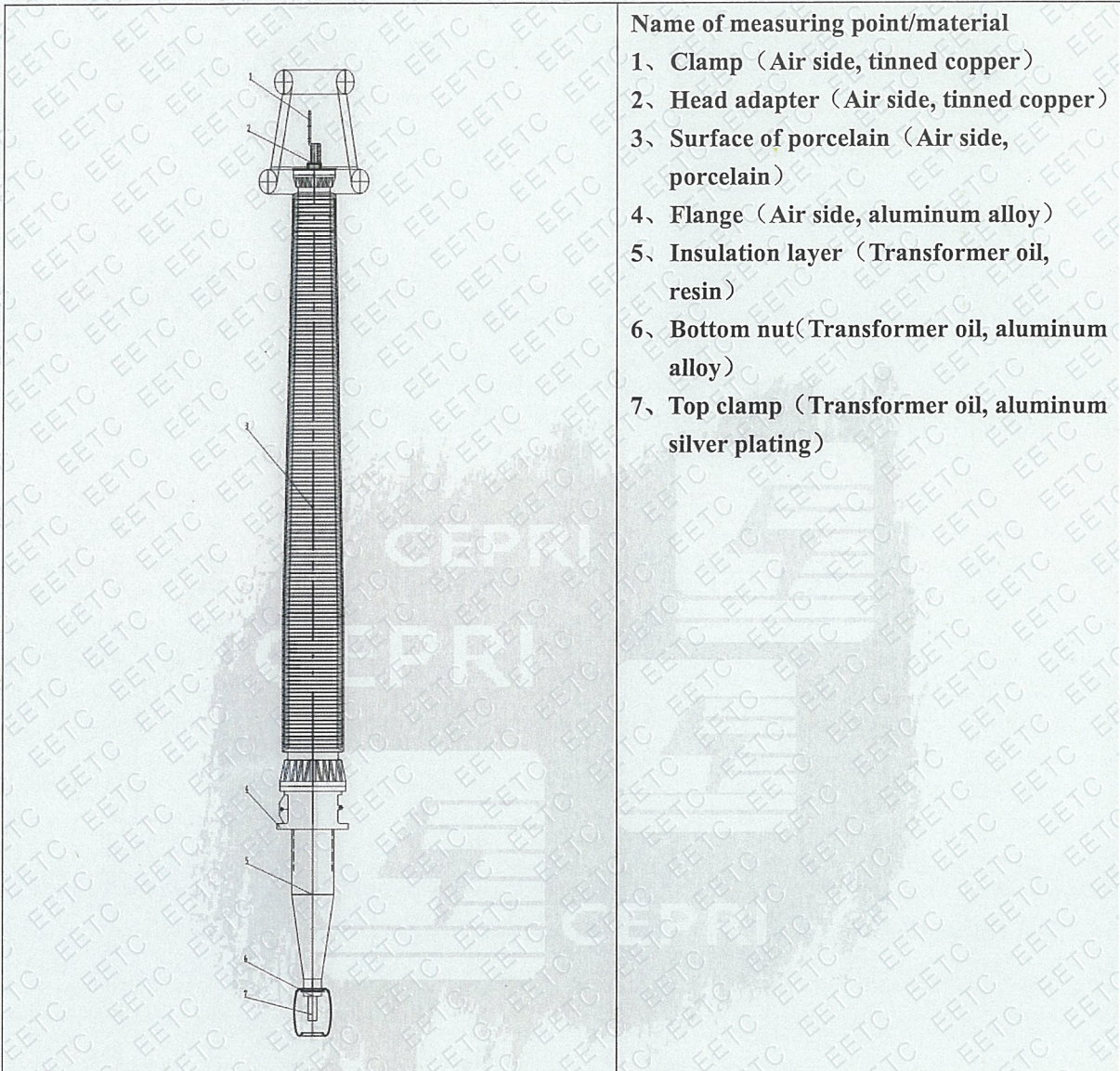
Current carrying and non-current carrying metal parts in contact with insulation: 75K/105°C

**13.2 Data**

Test current: 4000A      Ambient temperature: 14°C      Relative humidity: 37%

Thermocouple No.	Location	Description of component	Maximum temperature rise(K/°C)	Maximum temperature (K/°C)	
1	Clamp	Terminals to be connected to exterior conductors by screws or bolts (Tinned copper)	29/43	75/105	
2	Air Side	Current carrying and non-current carrying metallic parts in contact with insulation (Current carrying, tinned copper)	15/29	90/120	
3		Surface of porcelain	Porcelain	10/24	—
4	Oil side	Current carrying and non-current carrying metallic parts in contact with insulation (Non-current carrying, aluminum alloy)	25/39	90/120	
5		Core	epoxy resin	55/69	—
6		Bottom nut	Current carrying and non-current carrying metallic parts in contact with insulation (Non-current carrying, aluminum alloy)	58/72	90/120
7	Top clamp	Terminals to be connected to exterior conductors by screws or bolts (Aluminum silver plating)	59/73	75/105	





### 13.3 Test result

The test object passed the tests.



**14. Verification of thermal short-time current withstand****14.1 Reference standard requirement**

According to clause 8.9 of GB/T4109-2022 and IEC60137:2017 “Verification of thermal short-time current withstand”, the bushing shall be considered to be able to withstand the standard value of  $I_{th}$  if  $\theta_f$  does not exceed 180°C.

**14.2 Data**

$\theta_0$ (°C)	$\alpha$	$I_{th}$ (kA)	$t_{th}$ (s)	$S_t$ (cm <sup>2</sup> )	$S_e$ (cm <sup>2</sup> )
99	1.8	100	3	78.5	33.1
$\theta_f = \theta_0 + \alpha \times I_{th}^2 \times t_{th} / (S_t \times S_e) = 120$ (°C)					

where:  $\theta_0$ 、 $S_t$ 、 $S_e$  are provided by the client.

$\theta_0$ : the conductor temperature under continuous operation with  $I_r$  at an ambient temperature of 40°C ;

$\alpha$ : 1.8(k/s)/(kA/cm<sup>2</sup>) for aluminium;

$t_{th}$ : the rated duration as specified;

$I_{th}$ : the standard value as specified above;

$S_t$ : the total cross-section;

$S_e$ : the equivalent cross-section taking account of skin effect.

**14.3 Test result**

The test object passed the tests.

**15. Cantilever load withstand test****15.1 Reference standard requirement**

The load shall be applied perpendicular to the axis of the bushing at the mid-point of the air side terminal for 60s, loaded 5000N. No evidence of damage (deformation, rupture or leakage), and it shall withstand a repetition of all routine tests without significant change from previous results.

**15.2 Data**

Ambient temperature:13°C

Relative humidity:34%

Mounting	Location	Test load (N)	Duration (s)	Sample status
Mounted vertically	Air side	5000	60	No evidence of damage (deformation, rupture or leakage).

**15.3 Test result**

The test object passed the tests



**16. Verification of dimensions****16.1 Reference standard requirement**

The dimensions of the bushing under test shall be in accordance with the relevant drawings, particularly with regard to any dimensions to which special tolerances apply and to details affecting interchangeability.

**16.2 Data**

Ambient temperature: 16°C

Relative humidity: 35%

Test object	Item	Nominal value (mm)	Measured value (mm)
Silicon rubber	Creepage distance (Air side/Oil side)	20460/—	20880/1430
	Arcing distance (Air side/Oil side)	4680/1400	4710/1410
	Total length	7650	7680
Dimensions of parts for assembling and/or interconnection are in accordance with the relevant drawings			

**16.3 Test result**

The test object passed the tests.

**17. Measurement of dielectric dissipation factor ( $\tan\delta$ ) and capacitance at ambient temperature****17.1 Reference standard requirement**

The measured  $\tan\delta$  at the test voltage of 10kV,  $1.05U_m/\sqrt{3}$  and  $U_m$  shall not exceed 0.4%.

$\Delta\tan\delta$  shall not exceed 0.1% when the power frequency voltage increases from  $1.05U_m/\sqrt{3}$  to  $U_m$ .

**17.2 Data**

Ambient temperature: 17°C

Relative humidity: 35%

Modality of application	Test voltage(kV)	$\tan\delta$ (%)	$C_x$ (pF)
Between high voltage terminal and test tap	10	0.321	732.6
	333	0.331	732.6
	550	0.339	732.7

**17.3 Test result**

The test object passed the tests.



**18. Dry lightning impulse voltage withstand test**

**18.1 Reference standard requirement**

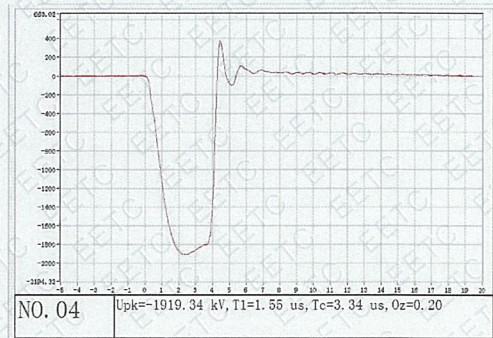
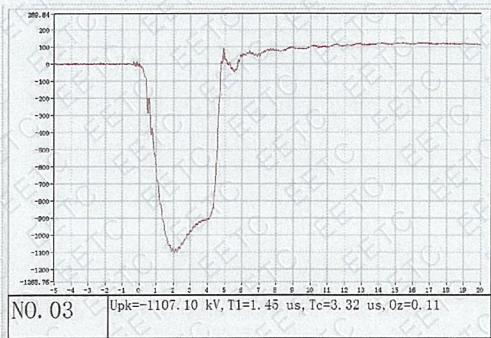
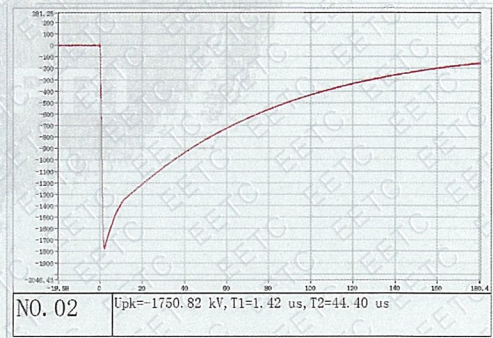
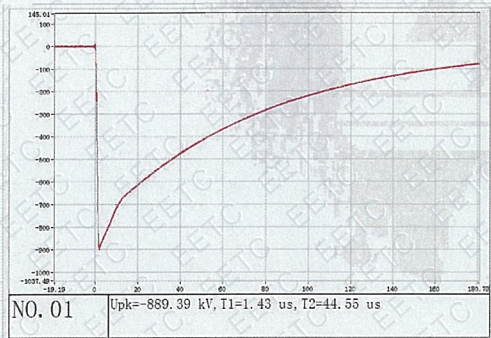
The bushing shall be subjected to 3 full lightning impulses of negative polarity at 1759kV (peak value). The bushing shall be subjected to 2 chopped lightning impulses of negative polarity at 1926kV (peak value). No flashover or puncture occurs.

**18.2 Data**

Ambient temperature: 17°C      Relative humidity: 35%      Ambient air pressure: 101.7kPa

No.	Voltage polarity	Test voltage (peak) (kV)	Chopped time (μs)	Waveform No.	Result
1	Negative lightning impulse	889	/	1	Pass
2	Negative lightning impulse	1751	/	2	Pass
3	Negative chopped impulse	1107	3.3	3	Pass
4	Negative chopped impulse	1919	3.3	4	Pass
5	Negative chopped impulse	1920	2.4	5	Pass
6	Negative lightning impulse	1750	/	6	Pass
7	Negative lightning impulse	1765	/	7	Pass

Classical test waveforms:



**18.3 Test result**

The test object passed the tests.



**19. Dry power-frequency voltage withstand test****19.1 Reference standard requirement**

The withstand voltage of 750kV is applied for 60s between the high voltage terminal of bushing and earth. No flashover or puncture occurs.

**19.2 Data**

Ambient temperature: 17°C      Relative humidity: 35%      Ambient air pressure: 101.7kPa

Modality of application	Test voltage/Frequency/Duration
Between high voltage terminal and earth	750kV/50Hz/60s

**19.3 Test result**

The test object passed the tests.

**20. Measurement of partial discharge quantity****20.1 Reference standard requirement**

Pre-stress voltage: 750kV      Test frequency: 50Hz

Test voltage: 550kV      Permissible PD level: 10pC

Test voltage: 476kV      Permissible PD level: 10pC

Test voltage: 333kV      Permissible PD level: 5pC

**20.2 Data**

Ambient temperature: 17°C      Relative humidity: 35%

Pre-stress voltage (kV)	750		
Test voltage (kV)	550	476	333
PD level (pC)	4	3	3

**20.3 Test result**

The test object passed the tests.

**21. Measurement of dielectric dissipation factor ( $\tan\delta$ ) and capacitance at ambient temperature****21.1 Reference standard requirement**

The measured  $\tan\delta$  at the test voltage of 10kV,  $1.05U_m/\sqrt{3}$  and  $U_m$  shall not exceed 0.4%.

$\Delta\tan\delta$  shall not exceed 0.1% when the power frequency voltage increases from  $1.05U_m/\sqrt{3}$  to  $U_m$ .

**21.2 Data**

Ambient temperature: 17°C      Relative humidity: 35%

Modality of application	Test voltage(kV)	$\tan\delta$ (%)	$C_x$ (pF)
Between high voltage terminal and test tap	10	0.325	732.8
	333	0.337	732.9
	550	0.342	732.9

**21.3 Test result**

The test object passed the tests.



**22. Tests of tap insulation****22.1 Reference standard requirement**

The withstand voltage of 2kV shall be applied for 60s between the test tap and earth. No flashover or puncture occurs.

Before and after the voltage withstand test,  $\tan\delta$  and capacitance with respect to earth shall be measured,  $C_x \leq 10000$  pF,  $\tan\delta \leq 5\%$ .

**22.2 Data**

Ambient temperature: 17°C

Relative humidity: 35%

Test voltage(kV)	Duration(s)	$\tan\delta$ (%)	$C_x$ (pF)
1	/	0.578	1112.3
2	60	Voltage withstand test between test tap and earth, no flashover or puncture occurred.	
1	/	0.587	1112.5

**22.3 Test result**

The test object passed the tests.

**23. Tightness test at the flange or other fixing device****23.1 Reference standard requirement**

For liquid-immersed bushings, the tank shall be filled with air or any suitable gas at a relative pressure of  $0.15\text{MPa} \pm 0.01\text{MPa}$  and maintained for 15 min, or oil at a relative pressure of  $0.1\text{MPa} \pm 0.01\text{MPa}$  and maintained for 12h, there shall be no leakage.

**23.2 Data**

Ambient temperature: 16°C

Relative humidity: 35%

Test pressure (MPa)	Duration (min)	Result
0.15(SF <sub>6</sub> )	15	No evidence of leakage

**23.3 Test result**

The test object passed the tests.

**24. Visual inspection and dimensional check****24.1 Reference standard requirement**

No surface defects shall be tolerated which could affect the satisfactory performance in service.

Dimensions of parts for assembling and/or interconnection shall be in accordance with the relevant drawings, checked by sampling.

**24.2 Data**

Visual inspection	No surface defects were detected.
Dimensional check	In accordance with the relevant draws.

**24.3 Test result**

The test object passed the tests.



Appendix A Object Parameters

A.1 Parameters

Highest voltage for equipment( $U_m$ )	550kV	Rated current(Ir)	4000A
Altitude	$\leq 1000m$	Rated frequency	50Hz
Rated insulation level	550/750/1675/1300kV	Rated short-time thermal current (r.m.s.)	100kA/3s
Insulating material	Impregnated fiber/ Porcelain	Temperature range	-40℃~40℃

A.2 Drawings

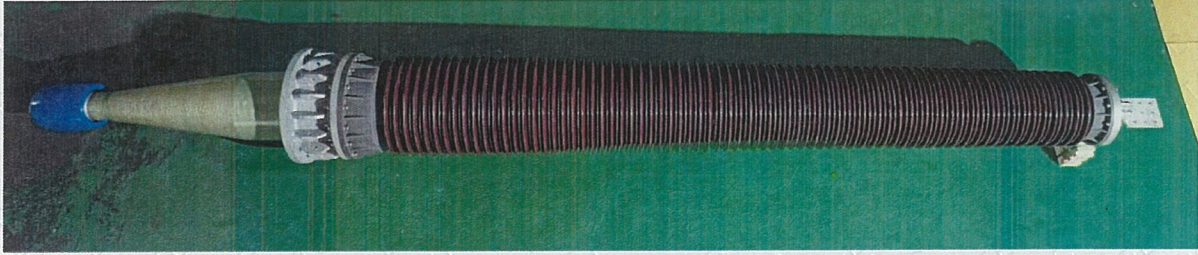
Lightning strikes at 1675kV  
Power frequency withstand voltage 750kV/1min  
Partial discharge UmkV<10pC  
Dielectric loss factor <0.4  
Pollution Grade IV / 31mm/kV(creepage distance >20460mm)  
Altitude: <1000m  
Bending load: >5kN  
Other requirements comply with the latest GB/T14109 and IEC60137

Model	QXBRCW-550/4000-4
Manufacturer	Shandong King High Voltage Electric Co., Ltd.
Product Name	Air capacitor transformer bushing with line
Scale	1:10
Picture No.	CBT55-1228
Product number	CBT1228
Design	Li Jiamin 2023.2.10
Check	Li Jiamin 2023.2.10
Standard	GB/T14109-2023.2.10
Process	
Approval	
Signature	
Date	
Weight	
Ratio	

研究  
20



## A.3 Photographs of test object



干式电容式变压器套管		雷电冲击电压kV/操作冲击电压kV/工频耐受电压kV	
Dry capacitive transformer bushing		BIL 1675 kV/SIL1300 kV/AC750kV	
型号 Type	QXBRGW-550/4000-4	爬电距离 Creepage Dis.	20460 mm
品号 Kat. NO.	CBT1228	重量 Weight	2850 kg
出厂编号 Serial No.	2303B001S	出厂日期 Date	2023. 3. 10
额定电压 Rated Voltage	550 kV	电容量 Capacitance	734 pF
额定电流 Rated Current	4000 A	介质损耗因数 Dielectric Dissipation Factor	0.34 %
山东七星高压电气有限公司 Shandong Qixing High Voltage Electric Co., Ltd.			

## A.4 Statement

- A.4.1 The test object offered by the client is a new, clean dry capacitive transformer bushing (with current carrying metal structure), including flange and all the other parts in normal operation. The major insulation of the bushing is resin-impregnated paper and the outer insulation is electric porcelain.
- A.4.2 The client declares that the stream-carrying conductor is of aluminum, and the sectional area is 7850mm<sup>2</sup>.
- A.4.3 The testing laboratory has checked that the drawings and other data submitted by the client can adequately represent the essential details and parts of the equipment to be tested, but isn't responsible for the accuracy of the detailed information.



## Appendix B Main Test Devices

No.	Name/ Type/ Specification	Serial No.	Measurement Range	Uncertainty / Accuracy class / Maximum Permissible Error	Calibration Institute	Valid Date
1	Power-frequency voltage measuring system	#111030 EETC09-1029	(40-1100)kV	3	National Center for High Voltage Measurement	2024.02.10
2	Impulse voltage measuring system	#17015-1 EETC09-1030	(200-3000)kV	3	National Center for High Voltage Measurement	2024.10.17
3	Multi-channel thermometer	#TPV91986 EETC09-1024	(0-100) °C	±2°C	GRG Metrology & Test Co., Ltd.	2024.03.16
4	Weight indicator	#1610099647 EETC09-1052	(50-1000)kg	5	GRG Metrology & Test Co., Ltd.	2024.02.01
5	Digital conductivity meter	#722014072713 EETC09-1043	(50-150) μs/cm	±5%	GRG Metrology & Test Co., Ltd.	2024.02.01
6	Partial discharge detector	#20071203 EETC09-1046	0-500pC	10	National Center for High Voltage Measurement	2024.01.29
7	Standard capacitor	#12001 EETC09-1033	(10-550)kV	C:50pF±1pF tgδ:1×10 <sup>-4</sup>	National Center for High Voltage Measurement	2024.03.27
8	High voltage bridge	#031302Z (EETC09-1038)	C:1:(1-1000) tgδ:±10%	C:± (0.005R <sub>N</sub> X+0.5%R <sub>N</sub> D) tgδ:±0.5%(D+0.01)	National Center for High Voltage Measurement	2024.10.19

