ASTA CERTIFICATE OF TYPE TESTS

Project No: G104245137 **Certificate No:** ASTA-TYPE-000159

Applicant: Zhejiang Jiangshan Transformer Co., Ltd.
No.48, Hushan Road, Jiangshan, Zhejiang Province, China

Apparatus: A three-phase, 21000/28000 kVA, ONAN/ONAF, 33/11 kV, 50 Hz, Category II, Dyn11, oil filled transformer. The high voltage winding has 17 taps and the principal tapping is tap 9b. The transformer is fitted with a Shanghai Huaming on-load tap changer.

Manufactured By: Zhejiang Jiangshan Transformer Co., Ltd.
No.48, Hushan Road, Jiangshan, Zhejiang Province, China

Test Report No: B20018

Designation: SFZ-28000/33

Date(s) of tests: 25 March to 1 April 2020

The apparatus which is representative of the designation, supplied drawings and photographs has been evaluated in accordance with:

IEC 60076-1: Edition 3.0 2011-04	**Clauses 11.1.2.1 i), 11.1.3 d), 11.1.3 e), 11.1.4 c), 11.1.4 d), 11.1.4 e), 11.1.4 h), 11.1.4 l), 11.1.4 n), 11.2 to 11.8, 11.10 and 11.12**
IEC 60076-2: Edition 3.0 2011-02	**Clauses 6 and 7**
IEC 60076-3: Edition 3.0 2013-07	**Clauses 9, 10, 11 and 13**
IEC 60076-5: Edition 3.0 2006-02	**Clause 4.2**
IEC 60076-10: Edition 1.0 2001-05	**Clauses 11 and 13**

(IEC 60076-10 Edition 1.0 is not covered by UKAS ISO 17065 accreditation)

And the STL Guide to IEC 60076, Issue 6.0, 1st June 2019, where applicable

The results are shown in the record of tests attached hereto. The values obtained and the general performance is considered to comply with the above Standard(s) and to justify the ratings assigned by the manufacturer as stated on the ratings page(s) of this Certificate. This Certificate applies only to the apparatus tested. Responsibility for conformity of any apparatus having the same or other designations rests with the Manufacturer.

Digitally signed by Dranga Iurii
Date: 2023.12.04 10:30:46 EET
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UKAS PRODUCT CERTIFICATION
010

C. Nick-Evans — Certification Engineer

Certification Officer

16 June 2020 — Date

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Email: asta@intertek.com

Project No: G104245137 **Certificate No:** ASTA-TYPE-000159

Verification of transformer

Limitations of use:

Characteristic verified	Clause/ Subclause	Verified Tests and Ratings	
Rated voltages, U_r	IEC 60076-1 Clause 5.4.1	U_r = (33±8x1.25%) / 11 kV	
No-load loss **and** **No-load current**	IEC 60076-1 Clause 11.1.3 e	15.10 kW at 90% rated voltage 30.94 kW at 110% rated voltage 0.07% at 90% rated voltage 0.41% at 110% rated voltage	
Rated power, S_r	IEC 60076-2 Clause 7	21000 kVA ONAN 28000 kVA ONAF	
Rated insulation level	IEC 60076-3* Clauses 9, 10, 11 and 13	HV: LV: LVN:	U_m 36 / LI 200 / LIC 220 / AC 85 kV U_m 12 / LI 75 / LIC 85 / AC 35 kV U_m 12 / LI 75 / AC 35 kV
Measurement of the power taken by the fan and liquid pump motors	IEC 60076-1	Verified	
Ability to withstand short-circuit	IEC 60076-5 Clause 4.2	Verified	
Sound pressure level @ 0.3 m ONAN	IEC 60076-10 Clause 11	60 dB(A), Guaranteed 70 dB(A)	
Sound power level ONAN	IEC 60076-10 Clause 13	78 dB(A), Guaranteed 87 dB(A)	
Sound pressure level @ 2.0 m ONAF	IEC 60076-10 Clause 11	62 dB(A), Guaranteed 70 dB(A)	
Sound power level ONAF	IEC 60076-10 Clause 13	84 dB(A), Guaranteed 90 dB(A)	

Note: *At the client's request, the LIC for the LV windings and AV test for all the windings were performed at higher value.

Project No: G104245137 **Certificate No:** ASTA-TYPE-000159

Certificate contents:

The following documents are attached to and form part of this certificate:

Documents:	Number of pages:
Test report no. B20018 dated 28 April 2020	99
Drawings	11

Certificate Revision Amendment Table:

Certificate Number	Issue Date	Amendment
ASTA-TYPE-000159	As front page	Initial Issue

APPARATUS TESTED: A three-phase, 21000/28000 kVA, ONAN/ONAF, 33/11 kV, 50 Hz, Category II, Dyn11, oil filled transformer. The high voltage winding has 17 taps and the principal tapping is tap 9b. The transformer is fitted with a Shanghai Huaming on-load tap changer.

STANDARD: IEC 60076-1: Edition 3.0 2011-04 Clauses 11.1.2.1 i), 11.1.3 d), 11.1.3 e), 11.1.4 c), 11.1.4 d), 11.1.4 e), 11.1.4 h), 11.1.4 l), 11.1.4 n), 11.2 to 11.8, 11.10 and 11.12
IEC 60076-2: Edition 3.0 2011-02 Clauses 6 and 7
IEC 60076-3: Edition 3.0 2013-07 Clauses 9, 10, 11 and 13
IEC 60076-5: Edition 3.0 2006-02 Clause 4.2
IEC 60076-10: Edition 1.0 2001-05 Clauses 11 and 13
And the STL Guide to IEC 60076, Issue 6.0, 1st June 2019, where applicable

MANUFACTURER: Zhejiang Jiangshan Transformer Co., Ltd. No.48, Hushan Road, Jiangshan, Zhejiang Province, China

TESTING LABORATORY: Shenyang Transformer Institute Co., Ltd. Transformer Laboratory (STRI-CTQC), No.18, Hushitai South Street, Shenbei New Area, Shenyang City, Liaoning, China

APPROVED BY: Hero Luo, ASTA Observer, Intertek China

ISSUED DATE: 28 April 2020

CONTENTS

Photographs: The following photographs are included in this document.

CONTENTS (continued)

Photographs: ***(continued)***

CONTENTS (continued)

Schedule of drawings: The following drawings were supplied by the client / manufacturer.

Drawing number	Issue Status		Description
	Revision	Date	
1.710.2718.1MP	-	Nov.15.2019	SFZ-28000/33 Nameplate
1.710.2718.01	-	Nov.15.2019	SFZ-28000/33 Transformer
1.710.2718.01-1	-	Nov.15.2019	SFZ-28000/33 Fitting list
6.600.2718.2	-	Nov.15.2019	SFZ-28000/33 HV coil
6.600.2718.1	-	Nov.15.2019	SFZ-28000/33 LV coil
5.517.2718.1	-	Nov.15.2019	SFZ-28000/33 HV lead
5.517.2718.2	-	Nov.15.2019	SFZ-28000/33 LV lead
5.641.2718.1	-	Nov.15.2019	SFZ-28000/33 Core assembly
5.700.2718.1	-	Nov.15.2019	SFZ-28000/33 The insulation of active part
5.312.2718.1	-	Nov.15.2019	SFZ-28000/33 Cover Plate
5.384.2718.1	-	Nov.15.2019	SFZ-28000/33 Maintank

All of the above drawings were supplied by the client and verified by the ASTA Observer as adequately representing the apparatus tested.

APPARATUS TESTED

A three-phase, 21000/28000 kVA, ONAN/ONAF, 33/11 kV, 50 Hz, Category II, Dyn11, oil filled transformer. The high voltage winding has 17 taps and the principal tapping is tap 9b. The transformer is fitted with a Shanghai Huaming on-load tap changer.

TRANSFORMER DETAILS

Manufacturer	: Zhejiang Jiangshan Transformer Co., Ltd.
Rating	: 21000/28000 kVA, ONAN/ONAF
Nominal voltage ratio	: 33/11 kV
Manufacturer's serial no.	: 113111910003
Product model	: SFZ-28000/33
Product type	: Three-phase transformer
Tapping	: ±8 steps of 1.25 %, (17 tap positions)
Connection symbol	: Dyn11
Rating plate impedance (75^{o}C)	: 12±7.5% at tap 9b
Cooling	: ONAN/ONAF
Dielectric properties	: HV : U_m 36 / LI 200 / LIC 220 / AC 85 kV LV : U_m 12 / LI 75 / LIC 85 / AC 35 kV LVN : U_m 12 / LI 75 / AC 35 kV
Oil mass	: 10000 kg
Transportation mass (with oil)	: 36140 kg
Total mass	: 45330 kg
Date of manufacture	: October 2019
Windings	: Circular
Winding material	: Wire (Copper)
Insulation system	: I-10 Oil

On-load tap changer

- Manufacturer	: Shanghai Huaming Electric Co., Ltd.
- Model number	: CVIII-350D/40.5-10193W
- Serial number	: V191252
- Rated motor voltage	: 240 V, 50 Hz
- Rated control voltage	: 240 V, 50 Hz

APPARATUS TESTED (Continued)

TRANSFORMER DETAILS

Nominal tapping ratios are detailed below. Tap 9b is the principal tap.

Tap Number	Rated HV Voltage V	Rated HV Current A @ 28000 kVA	Rated LV Voltage V	Rated LV Current A @28000 kVA
1	36300	445.3	10000	1469.6
2	35888	450.5		
3	35475	455.7		
4	35063	461.1		
5	34650	466.5		
6	34238	472.2		
7	33825	477.9		
8	33413	483.8		
9a	33000	489.9		
9b				
9c				
10	32588	496.1		
11	32175	502.4		
12	31763	509.0		
13	31350	515.7		
14	30938	522.5		
15	30525	529.6		
16	30113	536.8		
17	29700	544.3		

The transformer was fitted with several current transformers on the HV and LV windings. For detailed ratings refer to the test of the ratio and polarity of built-in current transformers

The transformer was fitted with one accessible connection for the insulation separating core and tank.

CLIENT

Zhejiang Jiangshan Transformer Co., Ltd.
No.48, Hushan Road, Jiangshan, Zhejiang Province, China

DATE OF RECEIPT OF APPARATUS

23 March 2020

ORDER NUMBER

QNS200225001

MANUFACTURER

Zhejiang Jiangshan Transformer Co., Ltd.
No.48, Hushan Road, Jiangshan, Zhejiang Province, China

WITNESSES OF THE TESTS:

Name	Organisation
Mr. Hero Luo	– ASTA Observer, Intertek Guangzhou
Mr. Yang Kewei	– Zhejiang Jiangshan Transformer Co., Ltd.
Mr. Xu Huajun	– Zhejiang Jiangshan Transformer Co., Ltd.
Mr. Shi Jiang	– Zhejiang Jiangshan Transformer Co., Ltd.

LABORATORY

The apparatus was tested at:

Shenyang Transformer Institute Co., Ltd. Transformer Laboratory (STRI-CTQC)
No.18, Hushitai South Street, Shenbei New Area, Shenyang City, Liaoning, China

The laboratory accreditation details are:

CNAS	**This Laboratory is accredited by China National Accreditation Service for Conformity Assessment against the requirements of ISO / IEC 17025:2017, Accredited No.: CNAS L0681**
INTERTEK ASTA RECOGNIZED LABORATORY	**This Laboratory is recognized by Intertek ASTA for Conformity Assessment to BS EN / ISO / IEC 17025:2017 and Regulations for ASTA Recognized Laboratories, Agreement No. 2019-RTL-L2-319**

SCHEDULE OF TESTS

The transformer was tested in accordance with the following standards:

IEC 60076-1: Edition 3.0 2011-04 Clauses 11.1.2.1 i), 11.1.3 d), 11.1.3 e), 11.1.4 c), 11.1.4 d), 11.1.4 e), 11.1.4 h), 11.1.4 l), 11.1.4 n), 11.2 to 11.8, 11.10 and 11.12
IEC 60076-2: Edition 3.0 2011-02 Clauses 6 and 7
IEC 60076-3: Edition 3.0 2013-07 Clauses 9, 10, 11 and 13
IEC 60076-5: Edition 3.0 2006-02 Clause 4.2
IEC 60076-10: Edition 1.0 2001-05 Clauses 11 and 13
And the STL Guide to IEC 60076, Issue 6.0, 1st June 2019, where applicable

Test	**Standard**	**Clause no.**	**Page no.**
Routine tests			
Measurement of winding resistance	IEC 60076-1	Clause 11.2	16 to 18
Measurement of voltage ratio and check of phase displacement	IEC 60076-1	Clause 11.3	19
Measurement of short-circuit impedance and load loss	IEC 60076-1	Clause 11.4	20 and 21
Measurement of no-load loss and current	IEC 60076-1	Clause 11.5	22 and 23
Tests on on-load tap-changers	IEC 60076-1	Clause 11.7	24
Check of the ratio and polarity of built-in current transformers	IEC 60076-1	Clause 11.1.2.1 i)	25
Leak testing with pressure for liquid-immersed transformers (tightness test)	IEC 60076-1	Clause 11.8	25
Check of core and frame insulation for liquid immersed transformers with core or frame insulation	IEC 60076-1	Clause 11.12	56
Insulation of auxiliary wiring (AuxW)	IEC 60076-3	Clause 9	26
Applied voltage test (AV)	IEC 60076-3	Clause 10	26
Induced voltage withstand test (IVW)	IEC 60076-3	Clause 11.2	27
Type tests			
Temperature rise type test	IEC 60076-2	Clauses 6 and 7	28 to 33
Including external hot spot temperature rise scan	-	-	29 and 32
Full wave lightning impulse test for the line terminals (LI)	IEC 60076-3	Clause 13.2	45 to 48
Determination of sound level	IEC 60076-10	Clauses 11 and 13	34 to 39
Measurement of the power taken by the fan and liquid pump motors	IEC 60076-1	Clause 11.1.3 d)	40

SCHEDULE OF TESTS

Test	Standard	Clause no.	Page no.
Measurement of no-load loss and current at 90 % and 110 % of rated voltage	IEC 60076-1	Clause 11.1.3 e)	22
Special tests			
Short-circuit withstand test	IEC 60076-5	Clause 4.2	41 to 44, and 49
Measurement of zero-sequence impedance(s) on three-phase transformers	IEC 60076-1	Clause 11.6	50
Vacuum deflection test for liquid immersed transformers	IEC 60076-1	Clause 11.9	51
Pressure deflection test on liquid immersed transformers	IEC 60076-1	Clause 11.10	52
Determination of capacitances windings-to-earth and between windings	IEC 60076-1	Clause 11.1.4 c)	53
Measurement of dissipation factor (tan δ) of the insulation system capacitances	IEC 60076-1	Clause 11.1.4 d)	54
Determination of transient voltage transfer characteristics	IEC 60076-1	Clause 11.1.4 e)	55
Measurement of d.c. insulation resistance between each winding to earth and between windings	IEC 60076-1	Clause 11.1.4 h)	56
Measurement of frequency response	IEC 60076-1	Clause 11.1.4 l)	57
Measurement of dissolved gasses in dielectric liquid	IEC 60076-1	Clause 11.1.4 n)	58
Chopped wave lightning impulse test (LIC)	IEC 60076-3	Clause 13.3	45 to 48
Lightning impulse test on a neutral terminal (LIN)	IEC 60076-3	Clause 13.4	48
Measurement of the harmonics of the no load current	-	-	59
Transition resistance measurement on on-load tap-changers	-	-	60

GENERAL TEST CONDITIONS

General

1. All the tests were performed on transformer serial no.: 113111910003.
   See Schedule of Tests, Pages 9 and 10

Routine tests and special tests

2. For all routine tests except the dielectric tests the transformer was supplied from a sinusoidal three-phase 50 Hz supply.
   For the applied voltage test (AV), the transformer was supplied from a sinusoidal 50 Hz single-phase supply.
   For the induced voltage withstand test, the transformer was supplied from a sinusoidal 200 Hz supply.

3. The HV and LV winding resistances were measured using a Baoding Jinyuan winding analyser d.c. bridge model JYR at 20 A before and after the short-circuit withstand tests.

4. The measurement of the d.c. insulation resistances between each winding to earth and between windings were measured using a Metrel HV insulation tester model MI2077 at 5000 V d.c. before and after the shot-circuit withstand tests.

5. The measurement of dissipation factor (tan δ) of the insulation system capacitances and determination of capacitances windings-to-earth and between windings were measured using a Shandong Fanhua automatic insulation diagnosis and analysing tester, model AI-6000K before and after the short-circuit withstand tests. The test voltage was 10 kV.

6. The voltage ratio and check of phase displacement were measured using a Baoding Siruite Multi-function turns ratio meter model SR2000B before and after the short-circuit withstand tests.

7. For the load loss tests, the power, voltages and currents were measured using an Acculoss measurement system ALMS 4100 before and after the short-circuit withstand tests.

   For the load loss test, the transformer's HV winding was energised with the LV winding short-circuited such that at least 50 % of rated current flowed in the HV winding.

   The short-circuit impedance and the load loss were calculated for a reference temperature of 75^{o}C.

8. For the no-load loss tests, the power, voltages and currents were measured using an Acculoss measurement system ALMS 4100 before and after the short-circuit withstand tests.

   For the no-load loss test the transformer's LV winding was energised at rated voltage with the HV windings open circuit in accordance with clause 11.5 of IEC 60076-1.

9. The transformer oil temperatures were measured via PT type thermocouples.

GENERAL TEST CONDITIONS

Routine tests *(Continued)*

10. In accordance with clause 7.2.3 of IEC 60076-3 and clause 4.2.7.4 a) of IEC 60076-5 the dielectric tests were performed in the following sequences before and after the short-circuit withstand tests:

Test Order	Before the short-circuit tests	After the short-circuit tests
A	Applied voltage test (AV)	Lightning impulse test (LI and LIC) and Lightning impulse test on a neutral terminal (LIN)
B	Induced voltage withstand test (IVW)	Applied voltage test (AV)
C	-	Induced voltage withstand test (IVW)

Temperature rise type test

11. The temperature rise results were calculated at a 75^{o}C reference temperature.

12. The temperature rise test was performed after the short-circuit withstand tests.

13. The transformer was tested in accordance with clause 7.3 of IEC 60076-2 using the short-circuit method.

    The test was performed first in ONAF condition and followed by ONAN conditions and each test was performed in two parts as follows:

    a) Total loss injection-
    The transformer HV winding was subjected to a test voltage sufficient to supply total losses with the LV winding short-circuited. The test power was maintained until the increase in top oil temperature rises were below 1 K per hour for a period of 3 hours.

    b) Rated current injection for the HV and LV windings-
    At the completion of part a), the test current was reduced to rated current for 1 hour followed by rapid disconnection of the test supply and the d.c. resistances of the windings measured to determine their maximum temperatures using the change of resistance method for the HV and LV windings.
    The corrections of clause 7.13 of IEC 60076-2 were used in determining the top oil, average oil and winding temperature rises.

14. An Acculoss measurement system ALMS 4100 was used to measure the current, voltages and power.

15. The HV (B-C) and LV (b-n) winding resistance were measured using two separate d.c. resistance bridges before and during the hot resistance shutdown.

16. Two PT type thermocouples were placed in the top oil pockets of the transformer.

17. The bottom radiators outlets temperatures were measured with PT type thermocouples placed on 4 outlet points of the radiator banks.

18. The ambient temperature was the average of 4 PT type thermocouples placed in oil pots each with approximately a 2 h time constant.
    The oil pots were positioned in the air at about 0.5 m from the intake of the coolers of the transformer in ONAF condition and positioned round the transformer located at about half the transformer's height and about 2 m from the transformer in ONAN condition.

GENERAL TEST CONDITIONS

Temperature rise type test *(Continued)*

19. The top oil temperature (θ_o) was determined from the average of the top oil pocket temperatures as per clause 7.4.1.

20. The bottom oil temperature (θ_b) was determined from the average of the bottom oil outlet temperatures of the radiator banks as per clause 7.4.2.

21. The average oil temperature was determined using clause 7.4.2: $\theta_{om} = (\theta_o + \theta_b)/2$

Determination of sound level

22. The sound pressure was measured in accordance with clause 11 of IEC 60076-10.

23. The sound pressure was measured after the short-circuit withstand tests.

24. The sound pressure level tests were performed with the transformer in a dimensioned 48.0 m wide 60.0 m deep by 38.0 m high, regularly shaped industrial room. The transformer positioned as shown in Figure 2.

25. Measurements were made using a Type 1 calibrated sound level meter complying with IEC 60651 and calibrated in accordance with clause 5.2 of ISO 3746 as follows:

    Sound level meter Hangzhou Aihua Type AWA6228, Serial no.: 00322954 and associated calibrator model type AWA6021A, Serial no.: 1012336 was used for the testing.
    The sound level calibrator was used before and after the test.

26. The sound level meter was hand-held for all sound level measurements. The operator stood to the side of the meter for each measurement.

27. Before and after the sound pressure level tests, the A-weighted sound level pressure level of the background noise was measured at 10 measuring positions at half height of the transformer height.

28. The transformer sound pressure level was measured under no-load conditions in accordance with clause 6.2 of IEC 60076-10.

29. The sound pressure level was measured around the prescribed contour at a distance of 0.3 m for ONAN condition and 2.0 m for ONAF condition from the transformer's principal radiating surface at half height of the transformer height.

30. The average sound pressure level and power level were calculated from the measured sound pressure levels in accordance with clauses 11 and 13 of IEC 60076-10.

Short-circuit withstand tests

31. Interpretation of IEC 60076-5 was taken from the STL Guide to IEC 60076, Issue 6.0, 1st June 2019.

32. An Acculoss measurement system ALMS 4100 was used in a three-phase circuit before the short-circuit withstand tests to determine short-circuit impedance and X/R ratio. These values were used in the calculation of short-circuit currents.

33. In accordance with clause 4.1.2 of IEC 60076-5, the short-circuit impedance of the transformer was calculated at a reference temperature of 75^{o}C.

GENERAL TEST CONDITIONS

Short-circuit withstand tests *(Continued)*

34. In accordance with clause 3.2.2 of IEC 60076-5 and at the client's request, the system impedance was calculated for a short-circuit apparent power of 1000 MVA at U_{sys} 33 kV.

35. For the short-circuit withstand tests, single-phase tests were performed. The transformer's HV winding was energised from a two-phase 50 Hz test supply between two line terminals. The pre-short-circuit method was used with the LV winding short-circuited. Nine consecutive short-circuit tests of nominal 0.25 s duration were performed in accordance with clause 4.2.5 of IEC 60076-5. See Figure 1 for the test circuit arrangement.

    *Remark: The short-circuit withstand tests was performed with single-phase test due to the limitations of the laboratory test equipment.

36. The reactance of the transformer was measured using a precision LCR analyser Jinan Fanghua model AI-6600B before the start of test and after each short-circuit withstand test.

37. For the short-circuit withstand tests, an earth fault detection device consisting of a current shunt between the tank of the transformer and the test station earth was used. The earth current was also monitored oscillographically.

38. The buchholz relay and oil pressure relays were monitored visually after each of the nine tests.

    Note: Neither relay operated during the testing

Lightning impulse test (LI, LIC and LIN)

39. The chopped wave lightning impulse test (LIC) was conducted after the short-circuit withstand tests on the HV and LV winding line terminals accordance with clause 13 of IEC 60076-3.

40. The lightning impulse test on a neutral terminal (LIN) was conducted after the short-circuit withstand tests on the LV neutral terminal by direct application of the full wave lightning impulse in accordance with clause 13 of IEC 60076-3.

41. For all tests the transformer frame, core and tank were solidly earthed.

42. The HV and LV windings of the transformer were tested with a single stage Marx type impulse generator as following:
    The HV winding line terminals of the transformer was tested at LI 200 kV / LIC 220 kV.
    The LV winding line terminals of the transformer was tested at LI 75 kV / LIC 85* kV.
    The HV winding neutral terminal of the transformer were tested at LI 75 kV.
    Note: *At the client's request, the LIC for the LV windings were performed at higher value

43. A full sequence of tests in accordance with clause 13.3 for chopped wave lightning impulse test on the HV and LV winding line terminals and clause 13.4 for lightning impulse test on a neutral terminal as appropriate to IEC 60076-3 were conducted on the transformer under test.

44. The chopped wave lightning impulse tests were applied to one HV winding line terminal at a time with the other two HV winding line terminals connected together via a current shunt to earth, and the other terminals connected together to earth directly.

45. The chopped wave lightning impulse tests were applied to one LV line terminal at a time with the other two LV line terminals and the LV neutral terminal via a 48 Ω resistor and a current shunt to earth, and the other terminals connected together to earth directly. First impulse tests sequence at the full voltage without the resistor and followed by an additional complete impulse tests sequence with the resistor except the chopped wave lightning impulse according to clause 13.1.4.1 of IEC 60076-3.

GENERAL TEST CONDITIONS

Lightning impulse test (LI, LIC and LIN) *(Continued)*

46. The full wave lightning impulses were applied to the LV neutral terminal with the LV winding line terminals connected together via a current shunt to earth, and other terminals connected together to earth directly.

47. Fault detection was by comparison of oscillographic voltage and current traces between the reference reduced level test and the full level tests.

Inspection

48. The transformer was detanked and the core and windings were inspected after the repeat routine tests, followed by the lightning impulse tests and the repeat dielectric tests that followed the short-circuit withstand tests.

TEST RESULTS

Transformer Serial No.: 113111910003

Measurement of winding resistance

HV winding	Phase	Before the short-circuit tests	After the short-circuit tests
Tap 1	A-B	0.13665 Ω	0.13392 Ω
	B-C	0.13726 Ω	0.13453 Ω
	C-A	0.13733 Ω	0.13464 Ω
	Average	0.13708 Ω	0.13436 Ω
Tap 2	A-B	0.13423 Ω	0.13150 Ω
	B-C	0.13483 Ω	0.13210 Ω
	C-A	0.13490 Ω	0.13225 Ω
	Average	0.13465 Ω	0.13195 Ω
Tap 3	A-B	0.13178 Ω	0.12912 Ω
	B-C	0.13240 Ω	0.12973 Ω
	C-A	0.13250 Ω	0.12989 Ω
	Average	0.13223 Ω	0.12958 Ω
Tap 4	A-B	0.12977 Ω	0.12717 Ω
	B-C	0.13046 Ω	0.12782 Ω
	C-A	0.13055 Ω	0.12797 Ω
	Average	0.13026 Ω	0.12765 Ω
Tap 5	A-B	0.12734 Ω	0.12479 Ω
	B-C	0.12801 Ω	0.12543 Ω
	C-A	0.12812 Ω	0.12557 Ω
	Average	0.12782 Ω	0.12526 Ω
Tap 6	A-B	0.12536 Ω	0.12285 Ω
	B-C	0.12603 Ω	0.12346 Ω
	C-A	0.12613 Ω	0.12362 Ω
	Average	0.12584 Ω	0.12331 Ω
Tap 7	A-B	0.12315 Ω	0.12051 Ω
	B-C	0.12357 Ω	0.12108 Ω
	C-A	0.12371 Ω	0.12123 Ω
	Average	0.12348 Ω	0.12094 Ω
Tap 8	A-B	0.12097 Ω	0.11854 Ω
	B-C	0.12158 Ω	0.11913 Ω
	C-A	0.12171 Ω	0.11928 Ω
	Average	0.12142 Ω	0.11898 Ω
Tap 9b	A-B	0.11795 Ω	0.11551 Ω
	B-C	0.11833 Ω	0.11587 Ω
	C-A	0.11816 Ω	0.11580 Ω
	Average	0.11815 Ω	0.11573 Ω
Tap 10	A-B	0.12101 Ω	0.11858 Ω
	B-C	0.12167 Ω	0.11922 Ω
	C-A	0.12175 Ω	0.11935 Ω
	Average	0.12148 Ω	0.11905 Ω

TEST RESULTS

Transformer Serial No.: 113111910003

Measurement of winding resistance (Continued)

HV winding	Phase	Before the short-circuit tests	After the short-circuit tests
Tap 11	A-B	0.12346 Ω	0.12096 Ω
	B-C	0.12410 Ω	0.12162 Ω
	C-A	0.12420 Ω	0.12172 Ω
	Average	0.12392 Ω	0.12143 Ω
Tap 12	A-B	0.12538 Ω	0.12288 Ω
	B-C	0.12608 Ω	0.12358 Ω
	C-A	0.12618 Ω	0.12366 Ω
	Average	0.12588 Ω	0.12337 Ω
Tap 13	A-B	0.12780 Ω	0.12526 Ω
	B-C	0.12851 Ω	0.12595 Ω
	C-A	0.12859 Ω	0.12603 Ω
	Average	0.12830 Ω	0.12575 Ω
Tap 14	A-B	0.12977 Ω	0.12718 Ω
	B-C	0.13046 Ω	0.12787 Ω
	C-A	0.13056 Ω	0.12793 Ω
	Average	0.13026 Ω	0.12766 Ω
Tap 15	A-B	0.13223 Ω	0.12962 Ω
	B-C	0.13286 Ω	0.13026 Ω
	C-A	0.13298 Ω	0.13031 Ω
	Average	0.13269 Ω	0.13006 Ω
Tap 16	A-B	0.13419 Ω	0.13152 Ω
	B-C	0.13483 Ω	0.13218 Ω
	C-A	0.13494 Ω	0.13221 Ω
	Average	0.13465 Ω	0.13197 Ω
Tap 17	A-B	0.13667 Ω	0.13394 Ω
	B-C	0.13727 Ω	0.13456 Ω
	C-A	0.13735 Ω	0.13459 Ω
	Average	0.13710 Ω	0.13436 Ω
Temperature-	Average oil	17.1 ^{o}C	12.3 ^{o}C
Date of Tests:		25 March 2020	28 March 2020

TEST RESULTS

Transformer Serial No.: 113111910003

Measurement of winding resistance (Continued)

LV winding	Phase	Before the short-circuit tests	After the short-circuit tests
-	a-n	5.295 mΩ	5.181 mΩ
	b-n	5.275 mΩ	5.159 mΩ
	c-n	5.323 mΩ	5.209 mΩ
	Average	5.298 mΩ	5.183 mΩ
Temperature-	Average oil	17.1 ^{o}C	12.3 ^{o}C
Date of Tests:		25 March 2020	28 March 2020

See Photograph no.: P001

TEST RESULTS

Transformer Serial No.: 113111910003

Measurement of HV to LV voltage ratio and check of phase displacement

Tap No.	Rated Primary Voltage	Nominal Ratio*	Difference from nominal ratio before the short-circuit tests (%)			Difference from nominal ratio after the short-circuit tests (%)		
			AB-ab	BC-bc	CA-ca	AB-ab	BC-bc	CA-ca
1	36300	3.3000	0.07	0.07	0.07	0.08	0.07	0.07
2	35888	3.2625	-0.02	-0.02	-0.03	-0.02	-0.02	-0.02
3	35475	3.2250	-0.12	-0.12	-0.13	-0.12	-0.12	-0.11
4	35063	3.1875	0.03	0.03	0.03	0.04	0.03	0.03
5	34650	3.1500	-0.07	-0.07	-0.07	-0.06	-0.07	-0.07
6	34238	3.1125	0.09	0.08	0.08	0.10	0.09	0.10
7	33825	3.0750	-0.02	-0.02	-0.02	-0.01	-0.02	-0.01
8	33413	3.0375	0.15	0.14	0.14	0.16	0.15	0.15
9b	33000	3.0000	0.05	0.05	0.05	0.05	0.04	0.05
10	32588	2.9625	-0.06	-0.06	-0.06	-0.05	-0.06	-0.05
11	32175	2.9250	-0.16	-0.17	-0.16	-0.16	-0.17	-0.17
12	31763	2.8875	0.01	0.00	0.01	0.01	0.00	0.00
13	31350	2.8500	-0.11	-0.10	-0.11	-0.11	-0.12	-0.11
14	30938	2.8125	0.07	0.07	0.07	0.06	0.05	0.06
15	30525	2.7750	-0.04	-0.04	-0.04	-0.04	-0.06	-0.05
16	30113	2.7375	0.14	0.14	0.14	0.14	0.12	0.13
17	29700	2.7000	0.03	0.02	0.02	0.01	0.00	0.01
Date of Tests			25 March 2020			28 March 2020		

*The rated voltage of the low voltage winding was 11000 V

The HV-LV of the transformer connection symbol was verified to be connected as Dyn11

See Photograph no.: P002

TEST RESULTS

Transformer Serial No.: 113111910003

Measurement of short-circuit impedance and load loss Tap 1 in ONAF condition

Tap 1	Before the short-circuit tests	After the short-circuit tests
Average line voltage	2393.0 V	2422.0 V
Average line current	233.05 A	235.55 A
Total power	30.81 kW	31.00 kW
Average oil temperature	17.7 °C	12.3 °C
Reference temperature	75 °C	75 °C
Load loss at reference temperature	122.75 kW	121.98 kW
Impedance at reference temperature	5.93 Ω	5.94 Ω
Percent impedance at reference temperature @ 28000 kVA	12.60 %	12.62 %
X/R ratio at reference temperature	28.73	28.96
Date of Tests:	25 March 2020	28 March 2020

Measurement of short-circuit impedance and load loss Tap 9b in ONAF condition

Tap 9b	Before the short-circuit tests	After the short-circuit tests
Average line voltage	2024.0 V	2074.0 V
Average line current	250.08 A	255.94 A
Total power	28.46 kW	29.33 kW
Average oil temperature	17.7 °C	12.3 °C
Reference temperature	75 °C	75 °C
Load loss at reference temperature	120.79 kW	120.08 kW
Impedance at reference temperature	4.67 Ω	4.68 Ω
Percent impedance at reference temperature @ 28000 kVA	12.01 %	12.03 %
X/R ratio at reference temperature	27.85	28.05
Date of Tests:	25 March 2020	28 March 2020

TEST RESULTS

Transformer Serial No.: 113111910003

Measurement of short-circuit impedance and load loss Tap 17 in ONAF condition

Tap 17	Before the short-circuit tests	After the short-circuit tests
Average line voltage	1792.0 V	1821.0 V
Average line current	281.02 A	285.26 A
Total power	32.62 kW	33.09 kW
Average oil temperature	17.7 °C	12.3 °C
Reference temperature	75 °C	75 °C
Load loss at reference temperature	139.13 kW	138.72 kW
Impedance at reference temperature	3.68 Ω	3.69 Ω
Percent impedance at reference temperature @ 28000 kVA	11.69 %	11.70 %
X/R ratio at reference temperature	23.52	23.61
Date of Tests:	25 March 2020	28 March 2020

See Photograph no.: P003

TEST RESULTS

Transformer Serial No.: 113111910003

Measurement of no-load loss and current at 90% and 110% rated voltage before the short-circuit tests

		At 90% rated voltage		At 110% rated voltage	
		U' mean scaled rms	U rms	U' mean scaled rms	U rms
Phase voltage	a-n	5788.4 V	5780.4 V	7081.3 V	7033.1 V
	b-n	5653.9 V	5681.1 V	6956.7 V	6938.9 V
	c-n	5705.4 V	5678.7 V	6920.5 V	6902.9 V
	Average	5715.9 V	5713.4 V	6986.2 V	6958.3 V
Phase current	a	1.156 A		6.552 A	
	b	0.754 A		4.772 A	
	c	1.250 A		6.832 A	
	Average	1.05 A = 0.07 % of rated I_r		6.05 A = 0.41 % of rated I_r	
Total power	P_m	15.09 kW		30.81 kW	
Total power	P_o	15.10 kW		30.94 kW	

Measurement of no-load loss and current at 100% rated voltage

		Before the short-circuit tests		After the short-circuit tests	
		U' mean scaled rms	U rms	U' mean scaled rms	U rms
Phase voltage	a-n	6409.5 V	6416.5 V	6441.6 V	6416.8 V
	b-n	6335.9 V	6321.6 V	6314.6 V	6307.6 V
	c-n	6308.5 V	6299.7 V	6296.3 V	6308.1 V
	Average	6351.3 V	6345.9 V	6350.8 V	6344.2 V
Phase current	a	1.775 A		1.757 A	
	b	1.272 A		1.247 A	
	c	1.907 A		1.959 A	
	Average	1.65 A = 0.11 % of rated I_r		1.65 A = 0.11 % of rated I_r	
Total power	P_m	20.51 kW		20.70 kW	
Total power	P_o	20.53 kW		20.72 kW	

TEST RESULTS

Transformer Serial No.: 113111910003

Measurement of no-load loss and current

Ambient conditions during the no-load tests were:

Ambient conditions	Before the short-circuit tests	After the short-circuit tests
Ambient air temperature	17.0 °C	12.0 °C
Oil average temperature	17.1 °C	12.3 °C
Relative humidity	24%	18%
Date of Tests	25 March 2020	28 March 2020

See Photograph no.: P004

TEST RESULTS

Transformer Serial No.: 113111910003

Tests on on-load tap changers

The transformer was fitted with a 17 step Shanghai Huaming Power Equipment Co., Ltd. tap changer type CVIII-350D/40.5-10193W.

The rated control voltage and the rated motor voltage of the tap changer was 240 V, 50 Hz.

The tap changer was subjected to the following four sequences before and after the short-circuit withstand tests.

The results were as shown below:

Sequence	Description	Result
a)	With the transformer de-energized, 8 complete cycles of operation were performed with the control circuit and motor energized at rated voltage	Passed
b)	With the transformer de-energized, 1 complete cycle of operation was performed with the control circuit and motor energized at 85% of rated voltage	Passed
c)	With the transformer energized at rated voltage, 1 complete cycle of operation was performed with the control circuit and motor energized at rated voltage	Passed
d)	With the LV winding short-circuited and the HV winding energized with rated current flowing through the tapped winding, 10 cycles of tap changer operation were completed from tap 7 to 11. Tap 9b was the principle tap.	Passed

Date of Tests before and after the short-circuit tests: 25 and 28 March 2020

TEST RESULTS

Transformer Serial No.: 113111910003

Check of the ratio and polarity of built-in current transformers

The transformer was fitted with the following built-in current transformers and the ratio and polarity were checked before and after the short-circuit withstand tests, the result is as shown below.

Phase	Type	Terminal connection	Current ratio	Accuracy class	Burden VA	Ratio check		Polarity
						Before the short-circuit tests	After the short-circuit tests	Before /after the short-circuit tests
HV A phase	LRB-35	1S1-1S2	600/5	5P20	20	601/5	601/5	Verified
HV B phase	LRB-35	1S1-1S2	600/5	5P20	20	601/5	601/5	Verified
HV C phase	LRB-35	1S1-1S2	600/5	5P20	20	601/5	601/5	Verified
	LR-35	2S1-2S2	600/5	1.0	20	612/5	612/5	Verified
LV a phase	LRB-11	1S1-1S2	1800/5	5P20	20	1796/5	1796/5	Verified
LV b phase	LRB-11	1S1-1S2	1800/5	5P20	20	1796/5	1796/5	Verified
LV c phase	LRB-11	1S1-1S2	1800/5	5P20	20	1796/5	1796/5	Verified
LV n phase	LRB-11	1S1-1S2	1800/5	5P20	20	1796/5	1796/5	Verified
	LRB-11	2S1-2S2	1800/5	5P20	20	1796/5	1796/5	Verified

Result: The ratio and polarity of built-in current transformers satisfied the requirements of the standard

Date of Tests before and after the short-circuit tests: 25 and 30 March 2020

Leak testing with pressure for liquid immersed transformers (tightness test)

A pressure of 30 kPa over the normal liquid pressure was applied from the top of oil conservator with the transformer equipped with all bushings and radiator banks, maintained for a period of 24 hours. After the test, there was no evidence of oil leakage.

Result: The transformer satisfied the requirements of the standard.

***Date of Tests**:* 30 to 31 March 2020

TEST RESULTS

Transformer Serial No.: 113111910003

Insulation of auxiliary wiring (AuxW)

The auxiliary wiring and the control circuitry of the transformer withstood 2 kV AC before and after the short-circuit withstand tests, applied for 60 s between the auxiliary wiring and the control circuitry terminals connected together and the tank.

The wiring for the built-in current transformers secondary windings withstood 2.5 kV AC applied for 60 s between the wiring and the tank before and after the short-circuit withstand tests.

Ambient conditions during the insulation of auxiliary wiring (AuxW) test were:

Ambient conditions	Before the short-circuit tests	After the short-circuit tests
Ambient air temperature	17.0 ^{o}C	13.0 ^{o}C
Relative humidity	24%	18%
Atmospheric pressure	1005 hPa	1012 hPa
Date of Tests	25 March 2020	28 March 2020

Applied voltage test (AV)

The HV winding satisfactorily withstood 85 kV (PK /√2) before and after the short-circuit withstand tests, applied for 60 s between the HV terminals and the LV terminals connected together with the tank, connected to earth.

The LV winding satisfactorily withstood 35 kV (PK /√2) before and after the short-circuit withstand tests, applied for 60 s between the LV terminals and the HV terminals connected together with the tank, connected to earth.

Ambient conditions during the applied voltage test (AV) were:

Ambient conditions	Before the short-circuit tests	After the short-circuit tests
Ambient air temperature	17.0 ^{o}C	13.0 ^{o}C
Relative humidity	24%	18%
Atmospheric pressure	1005 hPa	1012 hPa
Date of Tests	25 March 2020	28 March 2020

See Photograph no.: P005

Note: *At the client's request, the AV tests were performed at higher value

TEST RESULTS

Transformer Serial No.: 20145T02

Induced voltage withstand test (IVW)

The transformer satisfactorily withstood 22000 V before and after the short-circuit withstand tests at 200 Hz applied phase to phase for 30 s to the LV winding with the HV winding open-circuited and the neutral and frame earthed.

Ambient conditions during the induced voltage withstand test were:

Ambient conditions	Before the short-circuit tests	After the short-circuit tests
Ambient air temperature	17.0 °C	13.0 °C
Relative humidity	24%	18%
Atmospheric pressure	1005 hPa	1012 hPa
Date of Tests	25 March 2020	28 March 2020

See Photograph No.: P007

TEST RESULTS

Transformer Serial No.: 113111910003

Temperature rise type test - ONAF

Total rated losses of the transformer for temperature rise test at reference temperature 75°C

Supply to the HV winding and short-circuit the LV winding.

The total losses were equal to the sum of the load loss at reference temperature on tap 17 plus the no-load loss at rated voltage as after the short-circuit withstand tests.

Test	**Measured value**
Load loss at 75°C on Tap 17 in ONAF condition	138.72 kW
No-load loss	20.72 kW
Total loss at 75°C on Tap 17 in ONAF condition	159.44 kW
Rated HV current on Tap 17 in ONAF condition	544.32 A

a) Top oil temperature rise

Average injected power during last hour of the test = 159.53 kW
Total rated losses = 159.44 kW

Average ambient temperature during last hour of total rated losses = 13.9 °C
Top oil temperature during last hour of total rated losses, θ_o = 57.0 °C
Top oil temperature rise during last hour of total rated losses = 43.1 K

Average bottom oil temperature during last hour of total rated losses, θ_b = 29.7 °C
Average oil temperature during last hour of total rated losses, θ_{om} = 43.4 °C
Average oil temperature rise during last hour of total rated losses = 29.5 K

Corrected top oil temperature rise
$\Delta\theta_o = 43.1 \times (159.44 / 159.53)^{0.9} = 43.1$ K

Corrected average oil temperature rise
$\Delta\theta_{om} = 29.5 \times (159.44 / 159.53)^{0.9} = 29.5$ K

Top oil temperature rise: 43.1 K

Guaranteed limit for top oil rise: 60 K

TEST RESULTS

Transformer Serial No.: 113111910003

Temperature rise type test – ONAF (Continued)

External hot spot analysis

At the end of the injection of total losses an infrared scan was made on the transformer using a Fluke thermal imager, model Ti40.

Hot spot location was on LV phase b bushing turret.

Measured temperature:	82.1 °C
External ambient:	13.9 °C
Hot spot rise:	68.2 K

See Photograph no.: P009

b) Winding temperature rise for the HV and LV windings

Average HV current during last hour of the test	= 543.39 A
Rated HV current	= 544.32 A

Temperatures extrapolated back to time of switch off,

HV winding temperature	= 62.1 °C
LV winding temperature	= 65.7 °C

Ambient temperature at switch off	= 14.2 °C
Average oil temperature at switch off	= 42.4 °C

Winding temperature rises above average oil temperature at switch off

HV winding	= 62.1 – 42.4	= 19.7 K
LV winding	= 65.7 – 42.4	= 23.3 K

Corrected winding temperature rise above average oil temperature:

$\Delta\theta_W$ HV	= 19.7 x (544.32 / 543.39)$^{1.6}$	= 19.8 K
$\Delta\theta_W$ LV	= 23.3 x (544.32 / 543.39)$^{1.6}$	= 23.4 K

Corrected average oil temperature rise during last hour of the test to Part a) = 29.5 K

HV winding temperature rise = 19.8 + 29.5 = 49.3 K
LV winding temperature rise = 23.4 + 29.5 = 52.9 K

Guaranteed limit: 65 K

TEST RESULTS

Transformer Serial No.: 113111910003

Temperature rise type test - ONAF (Continued)

Determination of the hot-spot winding temperature rise

The hot-spot winding temperature rises were determined by the calculation by the manufacturer based on the temperature rise test results, and the results are as shown below:

The hot-spot factor provided by the manufacturer for HV and LV windings was 1.15.

HV winding (B-C) hot-spot temperature rise:	65.9 K	Limit 78 K
LV winding (b-n) hot-spot temperature rise:	70.0 K	Limit 78 K

Summary of temperature rise test:

Top oil temperature rise:	43.1 K	Limit 60 K
HV winding temperature rise:	49.3 K	Limit 65 K
LV winding temperature rise:	52.9 K	Limit 65 K

And the hot-spot winding temperature rises were all less than the limit.

Result: The transformer satisfied the requirements of the standard.

See Photograph nos.: P007 and P008

Date of Tests: 28 to 29 March 2020

TEST RESULTS

Transformer Serial No.: 113111910003

Temperature rise type test - ONAN

Total rated losses of the transformer for temperature rise test at reference temperature 75°C

Supply to the HV winding and short-circuit the LV winding.

The total losses were equal to the sum of the load loss at reference temperature on tap 17 plus the no-load loss at rated voltage as after the short-circuit withstand tests.

Test	**Measured value**
Load loss at 75°C on Tap 17 in ONAN condition	78.03 kW
No-load loss	20.72 kW
Total loss at 75°C on Tap 17 in ONAN condition	98.75 kW
Rated HV current on Tap 17 in ONAN condition	408.24 A

c) Top oil temperature rise

Average injected power during last hour of the test = 98.86 kW
Total rated losses = 98.75 kW

Average ambient temperature during last hour of total rated losses = 17.7 °C
Top oil temperature during last hour of total rated losses, θ_o = 62.8 °C
Top oil temperature rise during last hour of total rated losses = 45.1 K

Average bottom oil temperature during last hour of total rated losses, θ_b = 44.2 °C
Average oil temperature during last hour of total rated losses, θ_{om} = 53.5 °C
Average oil temperature rise during last hour of total rated losses = 35.8 K

Corrected top oil temperature rise
$\Delta\theta_o = 45.1 \times (98.75 / 98.86)^{0.9} = 45.1$ K

Corrected average oil temperature rise
$\Delta\theta_{om} = 35.8 \times (98.75 / 98.86)^{0.9} = 35.8$ K

Top oil temperature rise: 45.1 K

Guaranteed limit for top oil rise: 60 K

TEST RESULTS

Transformer Serial No.: 113111910003

Temperature rise type test – ONAN (Continued)

External hot spot analysis

At the end of the injection of total losses an infrared scan was made on the transformer using a Fluke thermal imager, model Ti40.

Hot spot location was on LV phase b bushing turret.

Measured temperature:	74.1 °C
External ambient:	17.7 °C
Hot spot rise:	56.4 K

See Photograph no.: P012

d) Winding temperature rise for the HV and LV windings

Average HV current during last hour of the test	= 408.38 A
Rated HV current	= 408.24 A

Temperatures extrapolated back to time of switch off,

HV winding temperature	= 67.4 °C
LV winding temperature	= 68.8 °C

Ambient temperature at switch off	= 17.9 °C
Average oil temperature at switch off	= 52.1 °C

Winding temperature rises above average oil temperature at switch off

HV winding	= 67.4 – 52.1	= 15.3 K
LV winding	= 68.8 – 52.1	= 16.7 K

Corrected winding temperature rise above average oil temperature:

$\Delta\theta_W$ HV	= 15.3 x (408.24 / 408.38)$^{1.6}$	= 15.3 K
$\Delta\theta_W$ LV	= 16.7 x (408.24 / 408.38)$^{1.6}$	= 16.7 K

Corrected average oil temperature rise during last hour of the test to Part a) = 35.8 K

HV winding temperature rise = 15.3 + 35.8 = 51.1 K
LV winding temperature rise = 16.7 + 35.8 = 52.5 K

Guaranteed limit: 65 K

TEST RESULTS

Transformer Serial No.: 113111910003

Temperature rise type test - ONAN (Continued)

Determination of the hot-spot winding temperature rise

The hot-spot winding temperature rises were determined by the calculation by the manufacturer based on the temperature rise test results, and the results are as shown below:

The hot-spot factor provided by the manufacturer for HV and LV windings was 1.15.

HV winding (B-C) hot-spot temperature rise:	62.7 K	Limit 78 K
LV winding (b-n) hot-spot temperature rise:	64.3 K	Limit 78 K

Summary of temperature rise test:

Top oil temperature rise:	45.1 K	Limit 60 K
HV winding temperature rise:	51.1 K	Limit 65 K
LV winding temperature rise:	52.5 K	Limit 65 K

And the hot-spot winding temperature rises were all less than the limit.

Result: The transformer satisfied the requirements of the standard.

See Photograph nos.: P010 and P011

Date of Tests: 29 March 2020

TEST RESULTS

Transformer Serial No.: 113111910003

Determination of sound level - @ 0.3 m in ONAN no-load condition

Test set up conditions

Height of transformer (including 0.6 m high base)	2.96 m
Sound level measurements made at 1/2 height	1.78 m
Transformer length	4.68 m
Transformer width	4.62 m
Prescribed contour perimeter, l_m	21.06 m
Measuring distance from prescribed contour	0.3 m
Distance between measuring points	0.96 m
Number of measurement points	22
Measurement point no.: 1	HV A phase bushing, numbered clockwise
Environmental conditions	
Temperature	12.3 ^{o}C
Relative humidity	20%
Atmospheric pressure	1016 hPa
Dates of Tests:	28 March 2020

Evaluation of sound level under rated current and short-circuit voltage conditions	
Transformer rated power, S_r	21 MVA
Reference power, S_p	1 MVA
$L_{WA,IN} = 39 + 18\log(S_r/S_p)$	62.8
Guarantee sound power level	87
Guarantee – $L_{WA,IN}$	=24.2 dB(A), > 8 dB(A)

As $L_{WA,IN}$ was more than 8 dB(A) below the guaranteed sound power level then load current sound level measurements were not required.

Sound level measurements were performed under no-load conditions.

TEST RESULTS

Transformer Serial No.: 113111910003

Measurement of sound level - @ 0.3 m in ONAN no-load condition (Continued)

The test was performed by energising the transformer from the LV windings under no-load conditions.

Test No.	Background Pressure Level (L_{bgAi}) dB(A)	
	Before the sound level test	After the sound level test
	1/2 Height	1/2 Height
1	30.1	30.9
2	29.7	29.5
3	29.0	30.2
4	30.2	30.7
5	29.4	30.1
6	29.5	29.8
7	30.4	29.7
8	30.1	30.6
9	30.5	31.2
10	30.8	30.9
Average	30.0 ($\overline{LbgA}$)	30.4 ($\overline{LbgA}$)

Position No.	Sound Pressure Level (L_{pAi}) dB(A)	Position No.	Sound Pressure Level (L_{pAi}) dB(A)
	1/2 Height		1/2 Height
1	58.7	12	58.1
2	57.1	13	60.5
3	62.3	14	56.4
4	62.0	15	59.6
5	63.4	16	58.9
6	62.4	17	56.7
7	62.9	18	62.6
8	61.5	19	61.0
9	60.8	20	58.0
10	59.4	21	56.3
11	57.2	22	57.9
Average	60.3 ($\overline{LpA0}$)		

TEST RESULTS

Transformer Serial No.: 113111910003

Measurement of sound level - @ 0.3 m in ONAN no-load condition (Continued)

Calculation of sound pressure level and sound power level

Prescribed contour perimeter	L_m = 21.06 m
Microphone positions spaced on the prescribed contour	22 positions at 0.96 m spaced
Height of transformer	2.36 m
Measurement surface	S = 62.13 m^2
Test chamber	α = 0.50
	S_V = 12902 m^2
	$A = \alpha S_V$ = 6451 m^2
	A/S= 103.84
	K = 10log (1+4/103.84) = 0.2 dB(A)

Sound pressure level:

Sound pressure level limit at 0.3 m under no-load conditions: 70 dB(A)

$$\overline{L_{pA}} = 10\lg\left(10^{0.1\overline{LpA0}} - 10^{0.1\overline{LbgA}}\right) - K = 60\,\text{dB(A)}$$

Sound power level:

Guaranteed sound power level limit under no-load conditions: 87 dB(A)

$$L_{WA} = \overline{L_{pA}} + 10\lg\frac{S}{S_0} = 78\ \text{dB(A)}$$

TEST RESULTS

Transformer Serial No.: 113111910003

Determination of sound level - @ 2.0 m in ONAF no-load condition

Test set up conditions

Height of transformer (including 0.6 m high base)	2.96 m
Sound level measurements made at 1/2 height	1.78 m
Transformer length	4.68 m
Transformer width	4.62 m
Prescribed contour perimeter, l_m	34.66 m
Measuring distance from prescribed contour	2.0 m
Distance between measuring points	0.96 m
Number of measurement points	36
Measurement point no.: 1	HV A phase bushing, numbered clockwise
Environmental conditions	
Temperature	12.3 ^{o}C
Relative humidity	20%
Atmospheric pressure	1016 hPa
Dates of Tests:	28 March 2020

Evaluation of sound level under rated current and short-circuit voltage conditions	
Transformer rated power, S_r	28 MVA
Reference power, S_p	1 MVA
$L_{WA,IN} = 39 + 18\log(S_r/S_p)$	65
Guarantee sound power level	90
Guarantee – $L_{WA,IN}$	=25 dB(A), > 8 dB(A)

As $L_{WA,IN}$ was more than 8 dB(A) below the guaranteed sound power level then load current sound level measurements were not required.

Sound level measurements were performed under no-load conditions.

TEST RESULTS

Transformer Serial No.: 113111910003

Measurement of sound level - @ 2.0 m in ONAF no-load condition (Continued)

The test was performed by energising the transformer from the LV windings under no-load conditions.

Test No.	Background Pressure Level (L_{bgAi}) dB(A)	
	Before the sound level test	After the sound level test
	1/2 Height	1/2 Height
1	31.9	29.7
2	31.6	30.1
3	31.1	29.3
4	31.4	30.0
5	31.6	29.2
6	30.7	29.8
7	31.3	30.4
8	30.3	30.2
9	30.3	30.3
10	30.5	30.8
Average	31.1 ($\overline{LbgA}$)	30.0 ($\overline{LbgA}$)

Position No.	Sound Pressure Level (L_{pAi}) dB(A)	Position No.	Sound Pressure Level (L_{pAi}) dB(A)
	1/2 Height		1/2 Height
1	61.5	19	61.7
2	61.3	20	62.0
3	61.7	21	61.2
4	62.6	22	61.5
5	61.8	23	60.8
6	61.0	24	61.2
7	62.4	25	63.6
8	61.3	26	62.2
9	61.1	27	61.4
10	60.0	28	61.7
11	62.9	29	62.4
12	62.4	30	61.3
13	63.7	31	61.1
14	62.8	32	62.6
15	63.4	33	62.4
16	62.8	34	61.5
17	62.5	35	62.3
18	62.4	36	61.8
Average	62.1 ($\overline{LpA0}$)		

TEST RESULTS

Transformer Serial No.: 113111910003

Measurement of sound level - @ 2.0 m in ONAF no-load condition (Continued)

Calculation of sound pressure level and sound power level

Prescribed contour perimeter	L_m = 34.66 m
Microphone positions spaced on the prescribed contour	36 positions at 0.96 m spaced
Height of transformer	2.36 m
Measurement surface	S = 151.12 m^2
Test chamber	α = 0.50
	S_V = 12902 m^2
	$A = \alpha S_V$ = 6451 m^2
	A/S= 42.69
	K = 10log (1+4/42.69) = 0.4 dB(A)

Sound pressure level:

Sound pressure level limit at 2.0 m under no-load conditions: 70 dB(A)

$$\overline{L_{pA}} = 10\lg\left(10^{0.1\overline{LpA0}} - 10^{0.1\overline{LbgA}}\right) - K = 62\,\text{dB(A)}$$

Sound power level:

Guaranteed sound power level limit under no-load conditions: 90 dB(A)

$$L_{WA} = \overline{L_{pA}} + 10\lg\frac{S}{S_0} = 84\ \text{dB(A)}$$

TEST RESULTS

Transformer Serial No.: 113111910003

Measurement of the power taken by the fan and liquid pump motors

There was a total of 4 sets of fans. In ONAN condition, all fans were turned off. In ONAF condition, all fans were turned on.

The manufacturer of the fans was Zhejiang ERG Technology Joint Stock Co., Ltd. The rating of the fans was 415 V, 50 Hz, 3-phase.

The power taken by the fans was measured as follows:

Product Fan	Type	Rated power W	Measured		
			Average (line) Voltage V	Average (line) Current A	Total power loss W
F1910290101	DBF2-7Q10	370	415.0	1.173	350.5
F1910290102	DBF2-7Q10	370	415.0	1.156	345.3
F1910290103	DBF2-7Q10	370	415.0	1.182	353.8
F1910290104	DBF2-7Q10	370	415.0	1.176	354.1

Date of Tests: 30 March 2020

TEST RESULTS

Transformer Serial No.: 113111910003

Short-circuit tests HV to LV winding, Supply A-B single-phase tests

Tapping voltage	-V	36300 / 11000		
Tap		1		
Transformer HV impedance at 75 °C	-Ω/phase	5.93		
X/R ratio at 75 °C		28.73		
Peak factor – Category II transformer		2.55		
Theoretical short-circuit phase currents:				
Asymmetrical peak - HV winding	-A	4396		
Average symmetrical - HV winding	-A	1724		
Asymmetrical peak - LV winding	-kA	25.13		
Average symmetrical - LV winding	-kA	9.85		
Test No.	B20018	S01-1	S01-2	S01-3
Single-phase test supply connection		A-B	A-B	A-B
Applied 2 phase HV line voltage during short-circuit tests	-kV	28.38	28.35	28.43
Duration	-s	0.25	0.25	0.25
Asymmetrical peak HV winding current*	-A	6710	6765	6875
Corrected asymmetrical peak HV winding phase current	-A	4473	4510	4583
Symmetrical HV winding current *	-A	2427	2448	2468
Corrected symmetrical HV winding phase current	-A	1618	1632	1645
Asymmetrical peak LV winding phase current -a	-kA	25.12	25.70	26.08
Symmetrical LV winding phase current -a	-kA	9.18	9.33	9.35
Percent change in reactance	- A phase	0.12	0.18	0.18
	- B phase	0.11	0.01	0.01
	- C phase	0.01	0.01	0.17
Date of Tests: 26 March 2020				

* The test supply was connected to the HV windings across A and B with the LV windings pre-set short-circuited

TEST RESULTS

Transformer Serial No.: 113111910003

Short-circuit tests HV to LV winding, Supply B-C single-phase tests

Tapping voltage	-V	33000 / 11000		
Tap		9b		
Transformer HV impedance at 75 °C	-Ω/phase	4.67		
X/R ratio at 75 °C		27.85		
Peak factor – Category II transformer		2.55		
Theoretical short-circuit phase currents:				
Asymmetrical peak - HV winding	-A	4870		
Average symmetrical - HV winding	-A	1910		
Asymmetrical peak - LV winding	-kA	25.31		
Average symmetrical - LV winding	-kA	9.92		
Test No.	B20018	S02-1	S02-2	S02-3
Single-phase test supply connection		B-C	B-C	B-C
Applied 2 phase HV line voltage during short-circuit tests	-kV	24.60	24.69	25.47
Duration	-s	0.25	0.25	0.25
Asymmetrical peak HV winding current*	-A	7169	7215	7465
Corrected asymmetrical peak HV winding phase current	-A	4779	4810	4977
Symmetrical HV winding current *	-A	2624	2628	2724
Corrected symmetrical HV winding phase current	-A	1749	1752	1816
Asymmetrical peak LV winding phase current -b	-kA	24.94	25.09	25.87
Symmetrical LV winding phase current -b	-kA	9.09	9.15	9.48
Percent change in reactance	- A phase	0.22	0.22	0.15
	- B phase	0.01	0.01	0.01
	- C phase	0.15	0.01	0.01
Date of Tests: 26 March 2020				

* The test supply was connected to the HV windings across B and C with the LV windings pre-set short-circuited

TEST RESULTS

Transformer Serial No.: 113111910003

Short-circuit tests HV to LV winding, Supply C-A single-phase tests

Tapping voltage	-V	29700 / 11000		
Tap		17		
Transformer HV impedance at 75 °C	-Ω/phase	3.68		
X/R ratio at 75 °C		23.52		
Peak factor – Category II transformer		2.55		
Theoretical short-circuit phase currents:				
Asymmetrical peak - HV winding	-A	5289		
Average symmetrical - HV winding	-A	2074		
Asymmetrical peak - LV winding	-kA	24.74		
Average symmetrical - LV winding	-kA	9.70		
Test No.	B20018	S03-1	S03-2	S03-3
Single-phase test supply connection		C-A	C-A	C-A
Applied 2 phase HV line voltage during short-circuit tests	-kV	21.43	21.18	21.40
Duration	-s	0.25	0.25	0.25
Asymmetrical peak HV winding current*	-A	8213	8258	8027
Corrected asymmetrical peak HV winding phase current	-A	5475	5505	5351
Symmetrical HV winding current *	-A	2959	2982	2920
Corrected symmetrical HV winding phase current	-A	1973	1988	1947
Asymmetrical peak LV winding phase current -c	-kA	25.55	25.47	25.43
Symmetrical LV winding phase current -c	-kA	9.21	9.22	9.13
Percent change in reactance	- A phase	0.19	0.19	0.19
	- B phase	0.01	0.01	0.01
	- C phase	0.19	0.28	0.37
Date of Tests: 26 March 2020				

* The test supply was connected to the HV windings across C and A with the LV windings pre-set short-circuited

TEST RESULTS

Transformer Serial No.: 113111910003

Short-circuit withstand tests (continued)

After test B20018-S03-3 the reactance was re-measured on the relevant taps, as indicated below:

Tap	Phase	Change in reactance %	Note: The maximum allowable percentage change in reactance for transformers with circular concentric coils with wire in accordance with clause 4.2.7.4 a) 5) of IEC 60076-5 is 2%.
1	A	0.18	
	B	0.17	
	C	0.01	
9b	A	0.22	At the completion of the tests the maximum change of the reactance measured was 0.37%.
	B	0.14	
	C	0.22	
17	A	0.19	
	B	0.01	
	C	0.37	

See Photograph nos.: P013 to P019

TEST RESULTS

Transformer Serial No.: 113111910003

Chopped wave lightning impulse test on HV winding

Chopped wave lightning impulse at LI 200 / LIC 220 kV on the HV winding.
Standard lightning impulse wave shape: 1.2 ± 30 % / 50 ± 20 % µs negative impulses
Chopped impulse wave, chopped between 3 µs and 6 µs

Terminal tested	**Test No.** B20018-	**Type of Impulse**	**Test Voltage kV**	**Wave shape (µs)**			**Result**
				T_1	T_2	T_c	
A Tap 1	L01	1 reduced level full wave	-109.5	1.50	52.0	-	Passed
	L02	1 full level full wave	-199.4	1.49	52.1	-	
	L03	1 reduced level chopped wave	-121.5	1.50	-	3.6	
	L04	1 full level chopped wave	-219.7	1.51	-	3.4	
	L05	1 full level chopped wave	-219.1	1.50	-	3.3	
	L06	1 full level full wave	-200.0	1.49	52.2	-	
	L07	1 full level full wave	-200.1	1.50	52.2	-	
B Tap 9b	L08	1 reduced level full wave	-109.1	1.52	49.2	-	Passed
	L09	1 full level full wave	-199.3	1.52	49.5	-	
	L10	1 reduced level chopped wave	-120.9	1.53	-	3.6	
	L11	1 full level chopped wave	-221.0	1.53	-	3.3	
	L12	1 full level chopped wave	-221.1	1.53	-	3.4	
	L13	1 full level full wave	-201.1	1.51	49.5	-	
	L14	1 full level full wave	-200.9	1.50	49.7	-	
C Tap 17	L15	1 reduced level full wave	-108.6	1.46	46.1	-	Passed
	L16	1 full level full wave	-197.3	1.46	46.2	-	
	L17	1 reduced level chopped wave	-120.3	1.47	-	3.7	
	L18	1 full level chopped wave	-219.0	1.47	-	3.4	
	L19	1 full level chopped wave	-220.4	1.46	-	3.3	
	L20	1 full level full wave	-199.8	1.46	46.2	-	
	L21	1 full level full wave	-199.4	1.46	46.2	-	
***Date of Tests**:* 27 March 2020							

TEST RESULTS

Transformer Serial No.: 113111910003

Chopped wave lightning impulse test on LV winding

Chopped wave lightning impulse at LI 75 / LIC 85 kV on the LV winding.
Standard lightning impulse wave shape: 1.2 ± 30 % / 50 ± 20 % µs negative impulses
Chopped impulse wave, chopped between 3 µs and 6 µs

Terminal tested	Test No. B20018-	Type of Impulse	Test Voltage kV	Wave shape (µs)			Result
				T_1	T_2	T_c	
a without the resistor on the neutral terminal	L22	1 reduced level full wave	-40.3	1.52	24.5	-	Passed
	L23	1 full level full wave	-73.8	1.50	24.4	-	
	L24	1 reduced level chopped wave	-44.4	1.51	-	4.1	
	L25	1 full level chopped wave	-85.0	1.50	-	3.5	
	L26	1 full level chopped wave	-84.2	1.50	-	3.8	
	L27	1 full level full wave	-74.3	1.50	24.2	-	
	L28	1 full level full wave	-74.9	1.50	24.2	-	
a with the resistor on the neutral terminal	L29	1 reduced level full wave	-40.3	1.50	47.6	-	Passed
	L30	1 full level full wave	-74.6	1.50	47.3	-	
	L31	1 full level full wave	-75.1	1.49	47.4	-	
	L32	1 full level full wave	-75.1	1.50	47.3	-	
b without the resistor on the neutral terminal	L33	1 reduced level full wave	-39.7	1.52	24.8	-	Passed
	L34	1 full level full wave	-75.3	1.50	24.8	-	
	L35	1 reduced level chopped wave	-44.8	1.52	-	4.1	
	L36	1 full level chopped wave	-85.3	1.51	-	3.8	
	L37	1 full level chopped wave	-85.3	1.51	-	3.1	
	L38	1 full level full wave	-75.1	1.50	24.8	-	
	L39	1 full level full wave	-75.1	1.51	24.9	-	
b with the resistor on the neutral terminal	L40	1 reduced level full wave	-40.1	1.50	47.6	-	Passed
	L41	1 full level full wave	-75.4	1.50	47.7	-	
	L42	1 full level full wave	-75.4	1.50	47.6	-	
	L43	1 full level full wave	-75.3	1.50	47.6	-	

TEST RESULTS

Transformer Serial No.: 113111910003

Chopped wave lightning impulse test on LV winding (Continued)

Terminal tested	**Test No.** B20018-	**Type of Impulse**	**Test Voltage kV**	**Wave shape (µs)**			**Result**
				T_1	T_2	T_c	
c without the resistor on the neutral terminal	L44	1 reduced level full wave	-40.1	1.50	24.5	-	Passed
	L45	1 full level full wave	-75.2	1.50	24.3	-	
	L46	1 reduced level chopped wave	-44.8	1.52	-	4.2	
	L47	1 full level chopped wave	-85.3	1.50	-	3.9	
	L48	1 full level chopped wave	-85.2	1.50	-	3.8	
	L49	1 full level full wave	-75.2	1.50	24.3	-	
	L50	1 full level full wave	-75.1	1.50	24.3	-	
c with the resistor on the neutral terminal	L51	1 reduced level full wave	-40.0	1.51	47.4	-	Passed
	L52	1 full level full wave	-75.3	1.49	47.2	-	
	L53	1 full level full wave	-75.2	1.49	47.2	-	
	L54	1 full level full wave	-75.2	1.49	47.3	-	
***Date of Tests**:* 27 March 2020							

TEST RESULTS

Transformer Serial No.: 113111910003

Lightning impulse test on a neutral terminal on LV winding neutral

Full wave lightning impulse at LI 75 kV on the LV winding neutral.
Standard lightning impulse wave shape: 1.2 ± 30 % / 50 ± 20 % µs negative impulses, and the front time up to a maximum of 13 µs.

Terminal tested	**Test No.** B20018-	**Type of Impulse**	**Test Voltage kV**	**Wave shape (µs)**			**Result**
				T_1	T_2	T_c	
n	L55	1 reduced level full wave	-41.8	1.41	45.2	-	Passed
	L56	1 full level full wave	-73.5	1.41	46.4	-	
	L57	1 full level full wave	-74.9	1.41	46.8	-	
	L58	1 full level full wave	-75.0	1.41	46.6	-	
***Date of Tests**:* 27 March 2020							

The ambient conditions during the chopped wave lightning impulse tests on the line terminals and lightning impulse tests on a neutral terminal were:

Ambient conditions	
Ambient air temperature	13.5 ^{o}C
Relative humidity	16%
Atmospheric pressure	1014 hPa

There were no flashovers, punctures or voltage collapses, and there was satisfactory agreement between the reference impulse and those recorded at the full test voltage.

See Photograph nos.: P020 to P024

Result: The transformer passed the chopped wave lightning impulse tests on the line terminals and lightning impulse tests on a neutral terminal and complied with the requirements in accordance with IEC 60076-3.

TEST RESULTS

Transformer Serial No.: 113111910003

Inspection

Following the completion of all tests the transformer was de-tanked and examined.

There was no visible damage to the structural integrity, the windings or the core.

Therefore, the transformer complied with the requirements of IEC 60076-5 clause 4.2.7.4.a) 3).

Date of final Inspection: 1 April 2020

Summary Clause 4.2.7.4.a) of IEC 60076-5

Transformer Category II

1. The results of the short-circuit withstand tests and the measurements and inspection checks during the tests did not reveal any faults.
2. The dielectric tests and the other routine tests were successfully repeated and the lightning impulse tests were successfully performed.
3. The inspection was satisfactory.
4. There were no traces of any electrical discharge.
5. The maximum change in reactance as a result of the short-circuit withstand tests did not exceed the specified limit.

Result: The transformer passed the short-circuit withstand tests.

TEST RESULTS

Transformer Serial No.: 113111910003

Measurement of zero-sequence impedance(s) on three-phase transformers

Test supply terminals	n - abc
Open-circuited terminals	ABC
Test voltage, *U*	68.38 V
Test current, *I*	396.44 A
Test current / phase	132.15 A
$Z_0 = 3\,U / I$	0.517 Ω
Ambient air temperature	12.0 ^{o}C
Oil average temperature	12.3 ^{o}C
Dates of Tests:	28 March 2020

Note: The zero-sequence impedance was measured after the short-circuit withstand tests.

TEST RESULTS

Transformer Serial No.: 113111910003

Vacuum deflection test for liquid-immersed transformers

A total of 13 reference measuring points were selected as close as possible to the points on the tank middle where the maximum deflection under vacuum was expected, considering the expected deflection. Refer to Figure 3 for detail. The distances from the reference points to the tank wall in a direction approximately normal to the tank were measured and recorded.

A vacuum pressure (absolute pressure ≤ 30 kPa) as specified by the client was applied to the transformer without the radiator banks and held at the level for 5 mins and the distances between the reference points and the tank wall were measured. The maximum difference between these measurements and the 1st measurements was the deflection under vacuum. The vacuum was then reduced back to the originally established level and a 3rd measurement of the distances was taken. The maximum difference between these measurements and the 1st measurements was the permanent deflection.

The selected measuring points and the measurements were as shown follow table.

	Reference value at normal pressure (mm)	Value at absolute pressure 30 kPa (mm)	Value after recovered normal pressure (mm)	Elastic deformation value (mm)	Permanent deflection (mm)
P1	293	300	293	7	0
P2	336	248	337	12	1
P3	400	406	400	6	0
P4	185	186	185	1	0
P5	184	185	184	1	0
P6	685	694	685	9	0
P7	710	717	710	7	0
P8	746	754	746	8	0
P9	148	149	148	1	0
P10	114	115	114	1	0
P11	289	292	289	3	0
P12	297	301	297	4	0
P13	301	303	301	2	0

Result: No visible deformation of the flanges, no weld or stiffener cracks and the permanent deflection after the vacuum was released did not exceed 1 mm. The transformer complied with the requirements of the standard.

Date of Tests: 31 March 2020

TEST RESULTS

Transformer Serial No.: 113111910003

Pressure deflection test for liquid-immersed transformers

A total of 13 reference measuring points were selected as close as possible to the points on the tank middle where the maximum deflection under pressure was expected, considering the expected deflection. Refer to Figure 3 for detail. The distances from the reference points to the tank wall in a direction approximately normal to the tank were measured and recorded.

A pressure of 60 kPa over the normal operational pressure as specified by the client was applied from the middle of the tank by compressed air and held at the level for 5 mins, and the distances between the reference points and the tank wall were measured. The maximum difference between these measurements and the 1st measurements was the deflection under pressure. The pressure was then released and a 3rd measurement of the distances was taken. The maximum difference between these measurements and the 1st measurements was the permanent deflection.

The selected measuring points and the measurements were as shown follow table.

	Reference value at normal pressure (mm)	Value at pressure 60 kPa (mm)	Value after recovered normal pressure (mm)	Elastic deformation value (mm)	Permanent deflection (mm)
P1	293	287	293	6	0
P2	336	327	335	10	1
P3	400	395	400	5	0
P4	185	184	185	1	0
P5	184	183	184	1	0
P6	685	678	685	7	0
P7	710	704	710	6	0
P8	746	738	746	8	0
P9	148	147	148	1	0
P10	114	113	114	1	0
P11	289	287	289	2	0
P12	297	294	297	3	0
P13	301	299	301	2	0

Result: There was no visible deformation of the flanges, no weld or stiffener cracks, no oil leaks, and the permanent deflection after the pressure was released did not exceed 1 mm. The transformer complied with the requirements of the standard.

Date of Tests: 31 March 2020

TEST RESULTS

Transformer Serial No.: 113111910003

Determination of capacitances windings-to-earth and between windings

The insulation system capacitances were measured at 10 kV, 50 Hz before and after the short-circuit withstand tests. These measurements were made during the dielectric dissipation factor test.

Condition	**Before the short-circuit tests**	**After the short-circuit tests**
	pF	pF
HV to LV and Earth	7363	7358
LV to HV and Earth	12070	12060
HV and LV to Earth	9208	9223
HV to LV	5112	5096
Environment conditions		
Temperature-air	17.0 ^{o}C	13.0 ^{o}C
Temperature-average oil	17.1 ^{o}C	12.3 ^{o}C
Humidity	24%	18%
Atmospheric pressure	1005 hPa	1012 hPa
Date of Tests:	25 March 2020	28 March 2020

HV : High voltage winding
LV : Low voltage winding

See Photograph no.: P025

TEST RESULTS

Transformer Serial No.: 113111910003

Measurement of dissipation factor (tan δ) of the insulation system capacitances

The dielectric dissipation factor of the transformer was measured before and after the short-circuit withstand tests at 10 kV, 50 Hz.

Condition	**Before the short-circuit tests**	**After the short-circuit tests**
	Tan δ (%)	Tan δ (%)
HV to LV and Earth	0.254	0.260
LV to HV and Earth	0.276	0.290
HV and LV to Earth	0.320	0.311
HV to LV	0.226	0.241
Environment conditions		
Ambient air temperature	17.0 ^{o}C	13.0 ^{o}C
Average oil temperature	17.1 ^{o}C	12.3 ^{o}C
Relative humidity	24%	18%
Atmospheric pressure	1005 hPa	1012 hPa
Date of Tests:	25 March 2020	28 March 2020

HV : High voltage winding
LV : Low voltage winding

See Photograph no.: P025

TEST RESULTS

Transformer Serial No.: 113111910003

Determination of transient voltage transfer characteristics

A low voltage impulse was applied to the HV phase A line terminal with phase B and C line terminals connected together to earth, and with resistance connected between the LV phase a and n. The HV winding was set on tap 9b.

Impulse wave shape	Actual wave shape
Conventional front time (µs)	1.36
Time to half value (µs)	53.8

Applied voltage HV to earth U_1 (V_{pk}) V	Connected resistance LV winding (a-n) Ω	LV winding (a-n) transmitted voltage U_2 (V_{pk}) V
100	50	9.17
100	100	13.41
100	200	16.18
100	300	19.91
100	400	27.62
100	800	28.95
100	Open circuit	53.72

Date of Tests: 30 March 2020

TEST RESULTS

Transformer Serial No.: 113111910003

Measurement of d.c. insulation resistance between each winding to earth and between windings and check of core and frame insulation for liquid immersed transformers with core or frame insulation

The d.c. insulation resistance of the transformer between each winding to earth and between windings were measured at 5000 V d.c., and the check of core and frame insulation for liquid immersed transformers with core or frame insulation were measured at 2500 V d.c. Both the tests were performed before and after the short-circuit withstand tests.

The results were:

Condition		Before the short-circuit tests			After the short-circuit tests		
		15 s	60 s	600 s	15 s	60 s	600 s
HV to LV and Earth	MΩ	39100	42200	385000	50800	62000	132000
LV to HV and Earth	MΩ	31100	49900	122000	32400	58500	139000
HV and LV to Earth	MΩ	43000	62000	-	59800	89200	-
HV to LV	MΩ	38600	60000	-	92300	129000	-
Core to earth	MΩ	-	34000	-	-	37800	-
Environment conditions							
Ambient air temperature		17.0 °C			13.0 °C		
Average oil temperature		17.1 °C			12.3 °C		
Relative humidity		24%			18%		
Atmospheric pressure		1005 hPa			1012 hPa		
Date of Tests:		25 March 2020			28 March 2020		

HV : High voltage winding
LV : Low voltage winding

See Photograph no.: P026

TEST RESULTS

Transformer Serial No.: 113111910003

Measurement of frequency response (Frequency Response Analysis or FRA)

Before and after the short-circuit withstand tests, a frequency response analysis (FRA) was made on the transformer on each winding by a Megger sweep frequency response analyzer, model No. FRAX 99.

The results are reported for information only as they are a signature of the transformer windings and are not classified as a rating.

Terminals Tested	**Test condition**	**FRA Oscillogram No.**	
	Tap	**Before the short-circuit test**	**After the short-circuit test**
A-B	1	B20018-FRA-01	B20018-FRA-10
B-C	1	B20018-FRA-02	B20018-FRA-11
C-A	1	B20018-FRA-03	B20018-FRA-12
A-B	9b	B20018-FRA-04	B20018-FRA-13
B-C	9b	B20018-FRA-05	B20018-FRA-14
C-A	9b	B20018-FRA-06	B20018-FRA-15
a-n	-	B20018-FRA-07	B20018-FRA-16
b-n	-	B20018-FRA-08	B20018-FRA-17
c-n	-	B20018-FRA-09	B20018-FRA-18

Date of Tests: 26 and 30 March 2020

TEST RESULTS

Transformer Serial No.: 113111910003

Measurement of dissolved gasses in dielectric liquid

During various stages of the testing process, oil samples were taken from the bottom of the main tank for electrical and chemical analysis. The results are as shown below:

Quantity	Sample 1	Sample 2	Sample 3	Sample 4
Tan δ at 90 °C (%)	0.26	0.27	-	-
Electric strength (kV)	63.6	62.1	-	-
Water content (mg/L)	8	8	-	-
DGA (μL/L)				
Σ_{CH}	0.21	0.25	0.36	0.35
H_2	0.31	0.34	3.07	2.99
CO	1.30	1.32	5.07	5.45
CO_2	147.53	149.39	288.46	213.74
CH_4	0.21	0.25	0.36	0.35
C_2H_6	0.00	0.00	0.00	0.00
C_2H_4	0.00	0.00	0.00	0.00
C_2H_2	0.00	0.00	0.00	0.00
	Before all the tests	After the short-circuit tests and repeated routine tests	Before the temperature rise test	After the temperature rise test
Date of sample	25 Mar. 2020	28 Mar. 2020	29 Mar. 2020	31 Mar. 2020

TEST RESULTS

Transformer Serial No.: 113111910003

Measurement of the harmonics of the no-load current

Series	I_a (% H1)	I_b (% H1)	I_c (% H1)
1	100	100	100
2	2.53	6.29	6.46
3	17.83	28.93	10.88
4	1.71	4.39	4.57
5	30.89	26.59	25.57
6	2.45	1.21	3.26
7	16.94	15.92	13.56
8	0.79	1.90	1.98
9	1.95	5.44	2.44
10	0.52	0.93	1.12
11	3.93	3.53	4.20
12	0.46	0.30	0.63
13	2.04	1.86	1.91
14	0.13	0.30	0.32
15	0.50	1.07	0.34
16	0.11	0.20	0.23
17	0.70	0.63	0.53
18	0.06	0.09	0.15
19	0.41	0.27	0.30
20	0.11	0.11	0.14
21	0.11	0.11	0.07
22	0.16	0.14	0.10
23	0.26	0.06	0.20
24	0.08	0.13	0.08
25	0.16	0.17	0.10
26	0.07	0.10	0.06
Dates of Tests: 28 March 2020			

Note: The harmonics of the no-load current were measured after the short-circuit withstand tests.

TEST RESULTS

Transformer Serial No.: 113111910003

Transition resistance measurement on on-load tap-changers

The transformer was fitted with a 17 step Shanghai Huaming Power Equipment Co., Ltd. tap-changer type CVIII-350D/40.5-10193W.

The transition resistances were measured phase by phase by a Baoding Jinyuan on-load tap-changer tester model no. JYK-I with the tap-changer switched from tap 6 to tap 7 and from tap 7 to tap 6. The results are as shown below and refer to Figures 4 and 5:

Tap change direction	Transition duration (ms)			Transition resistance (Ω)		
	Phase A	Phase B	Phase C	Phase A	Phase B	Phase C
6 to 7	81.5	81.7	81.2	1.5	1.6	1.4
7 to 6	81.5	78.0	82.0	1.5	1.6	1.6

Dates of Tests: 28 March 2020

Figure 1

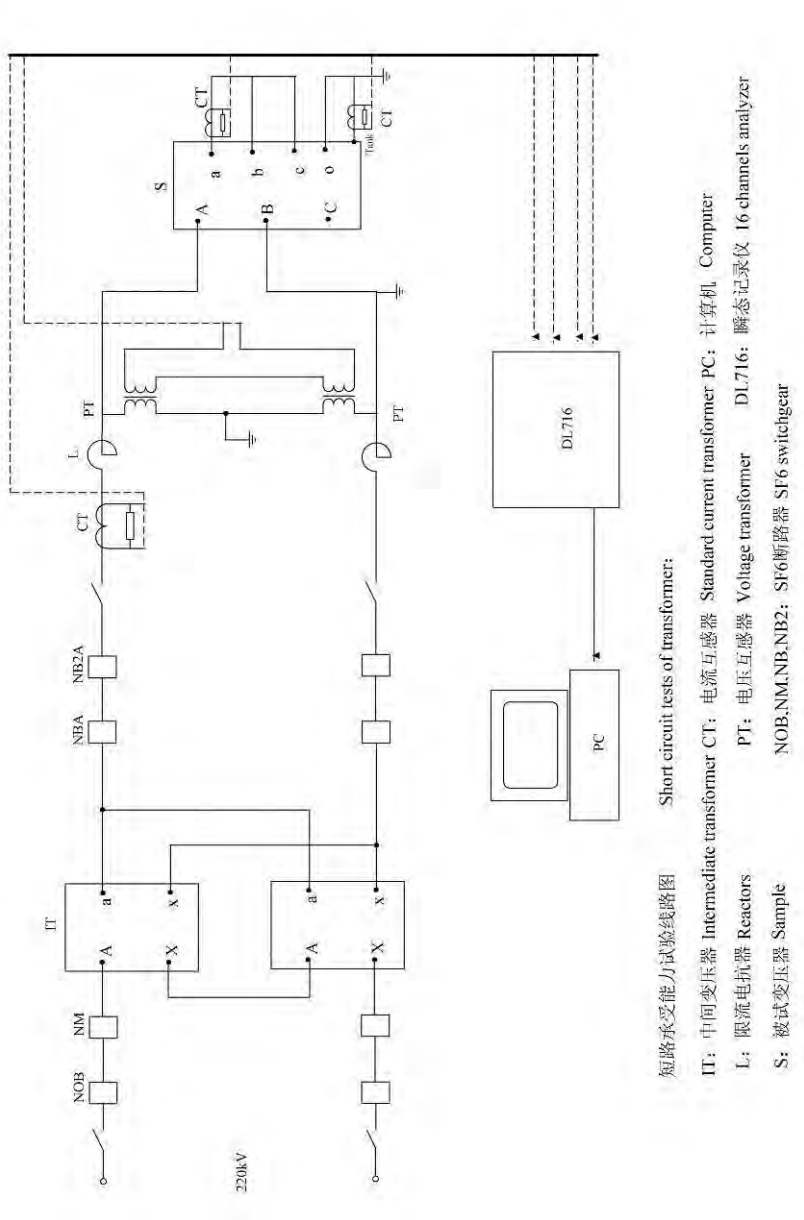

CT
CT
S
a
b
c
o
A
B
C
PT
PT
L
CT
NB2A
NBA
IT
a
x
A
X
NM
NOB
220kV
DL716
PC
短路承受能力试验线路图 Short circuit tests of transformer:
IT：中间变压器 Intermediate transformer CT：电流互感器 Standard current transformer PC：计算机 Computer
L：限流电抗器 Reactors PT：电压互感器 Voltage transformer DL716：瞬态记录仪 16 channels analyzer
S：被试变压器 Sample NOB,NM,NB,NB2：SF6断路器 SF6 switchgear

Figure 2

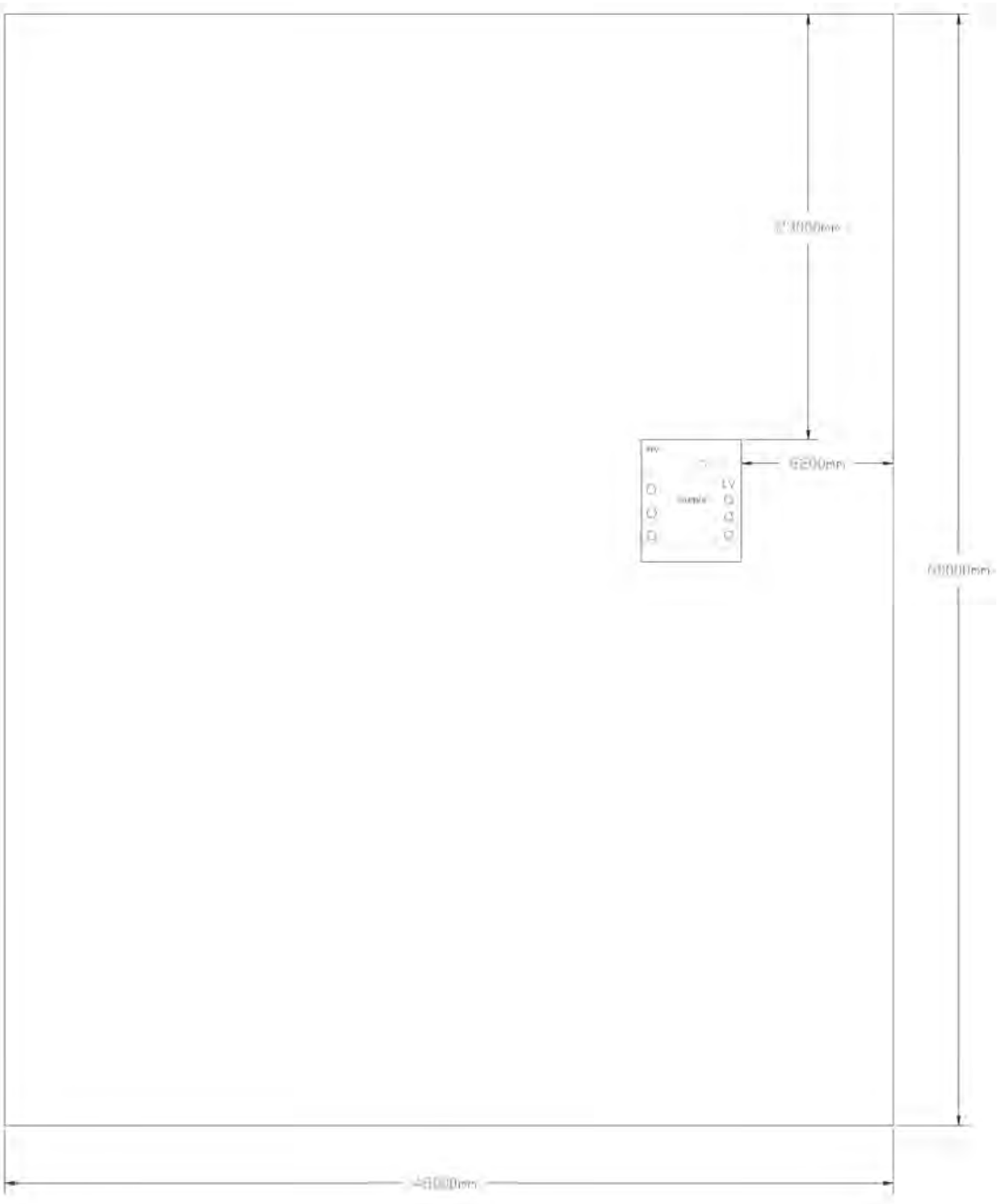


Figure 3

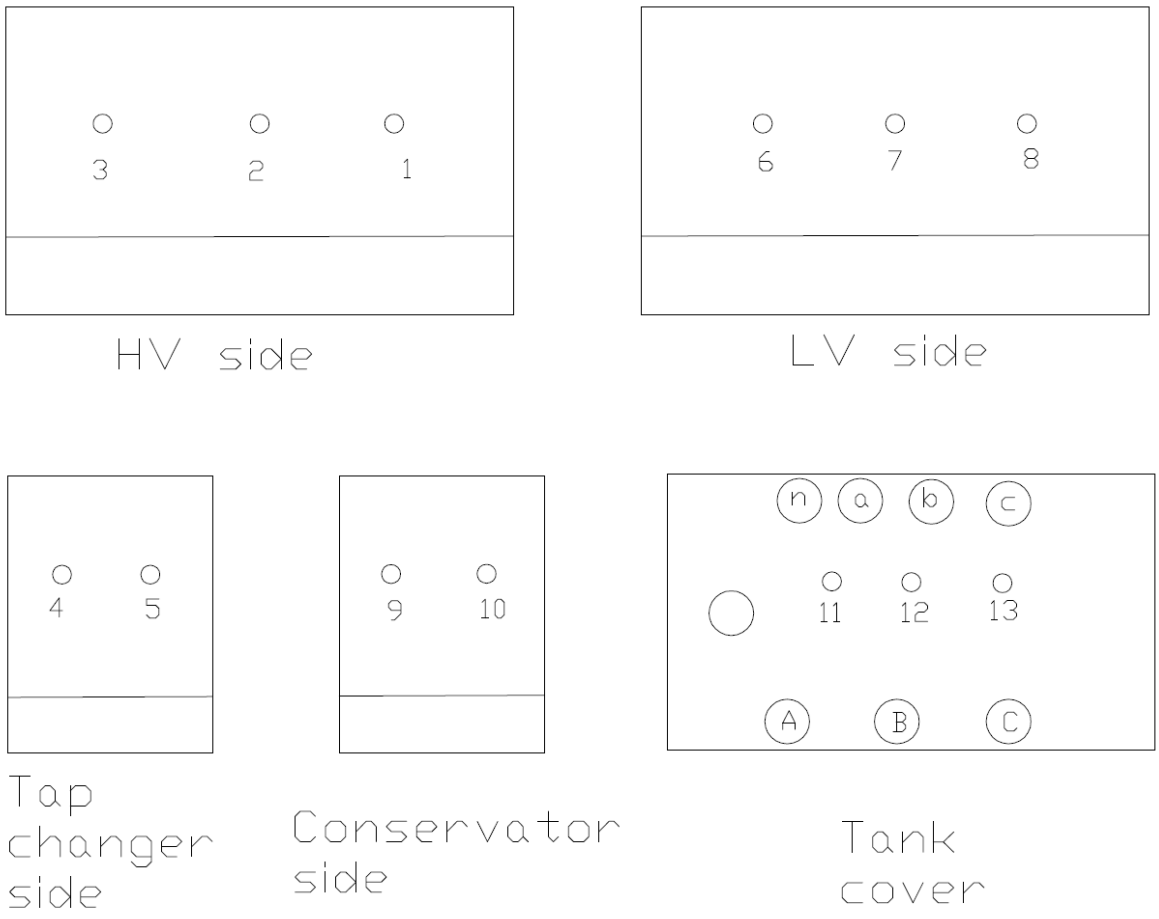
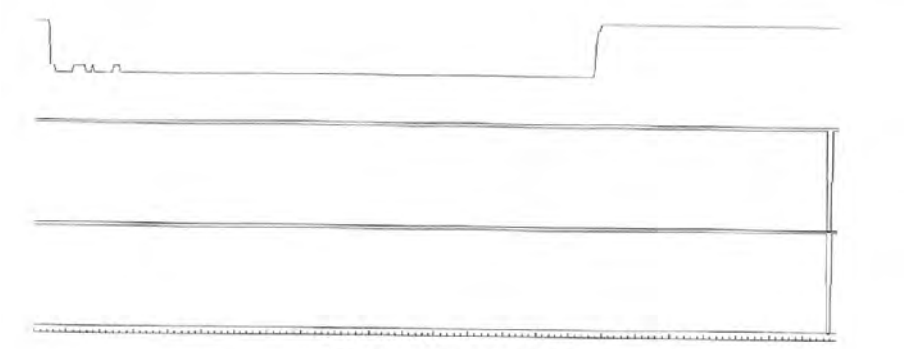
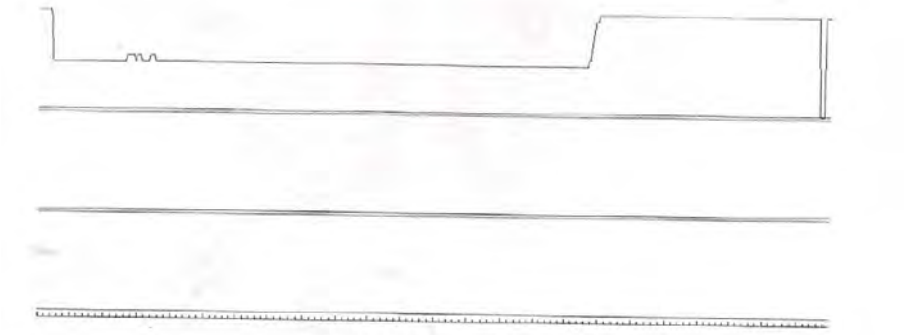

3
2
1
HV side
6
7
8
LV side
4
5
Tap changer side
9
10
Conservator side
n
a
b
c
11
12
13
A
B
C
Tank cover

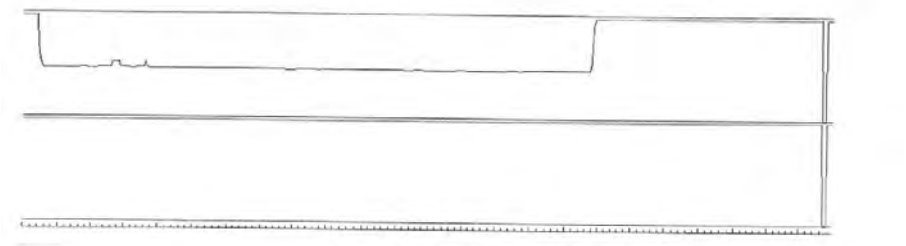
Figure 4



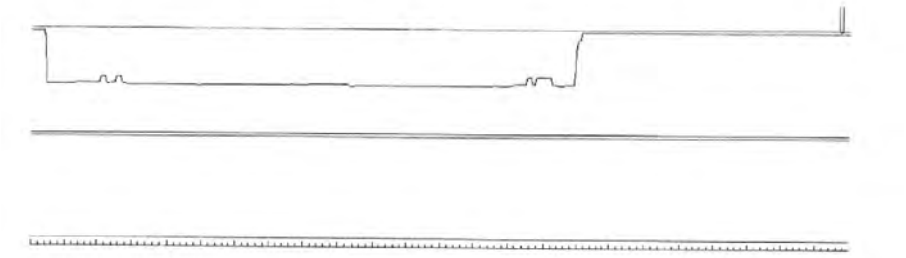
Phase A Tap 6 to tap 7



Phase A Tap 7 to tap 6

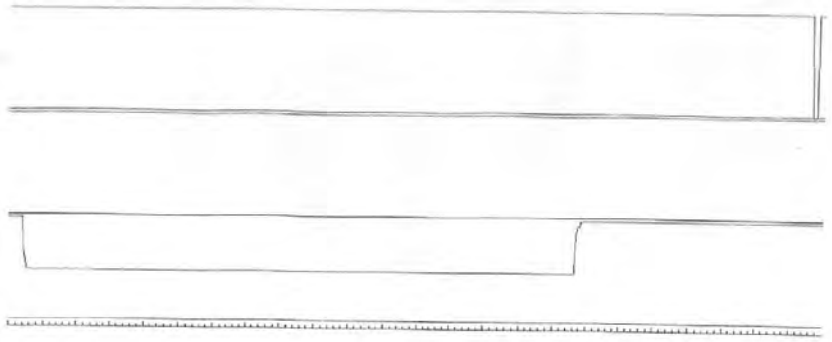


Phase B Tap 6 to tap 7

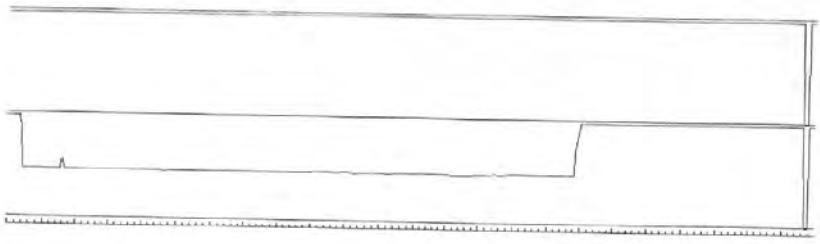


Phase B Tap 7 to tap 6

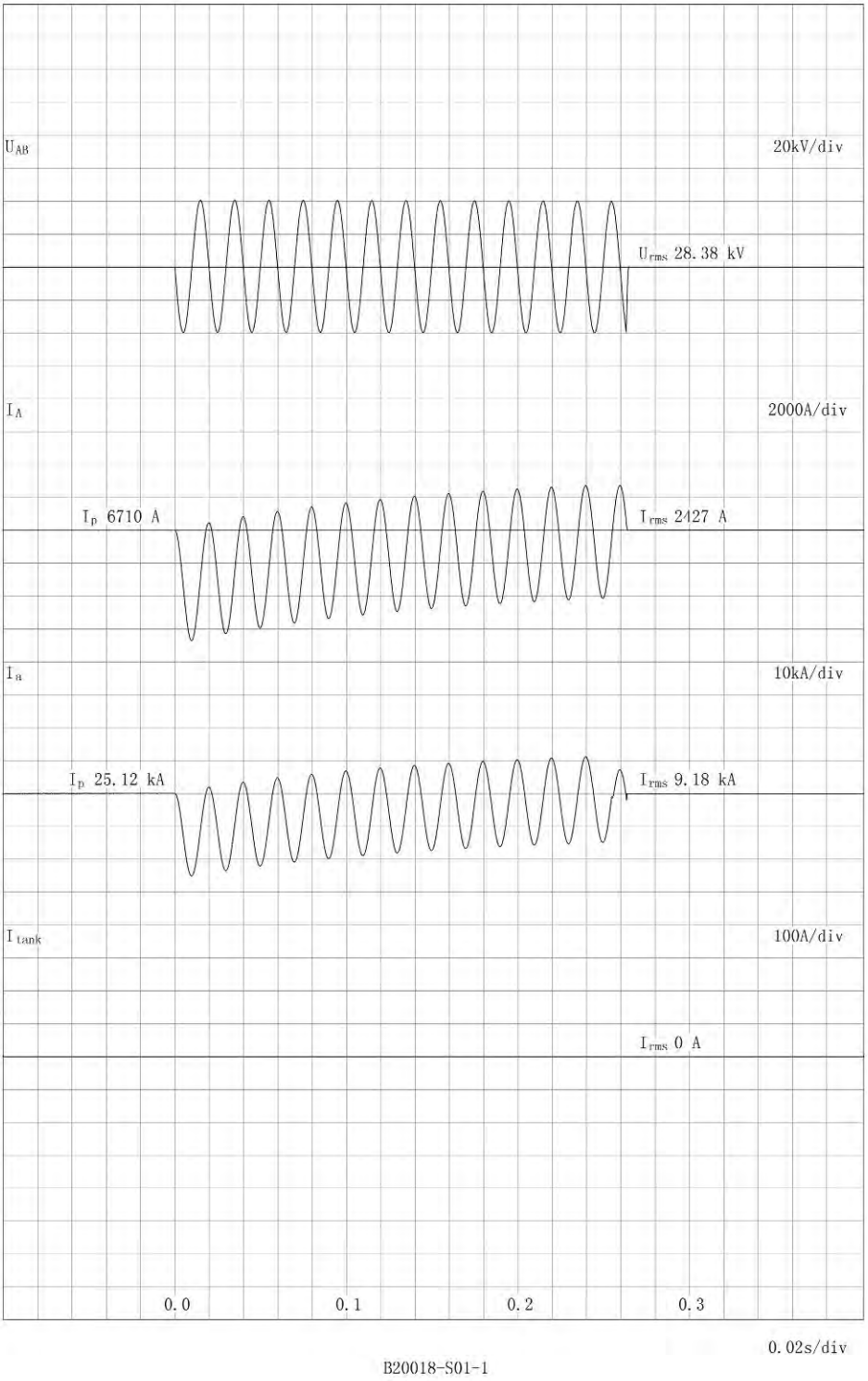
Figure 5



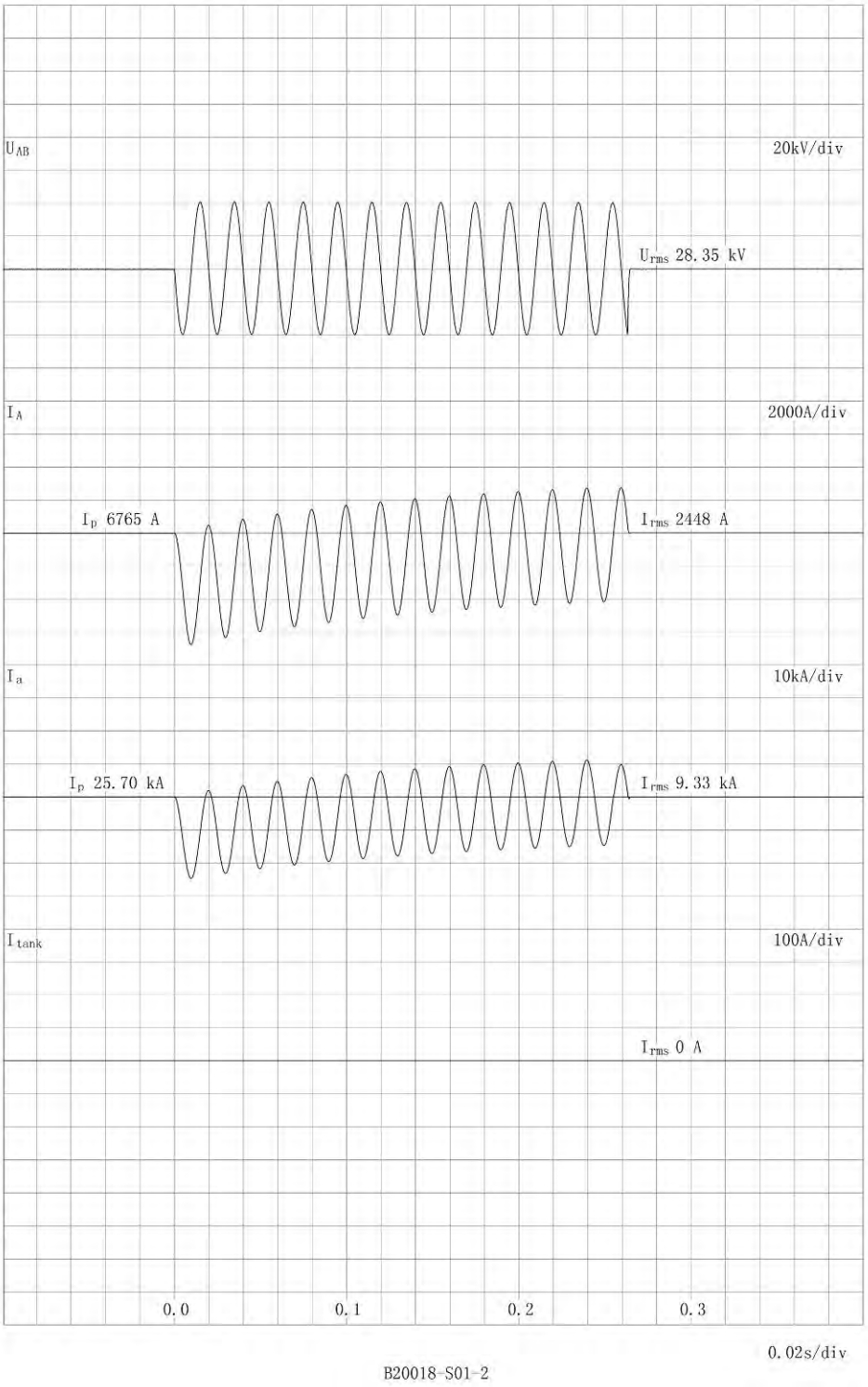
Phase C Tap 6 to tap 7

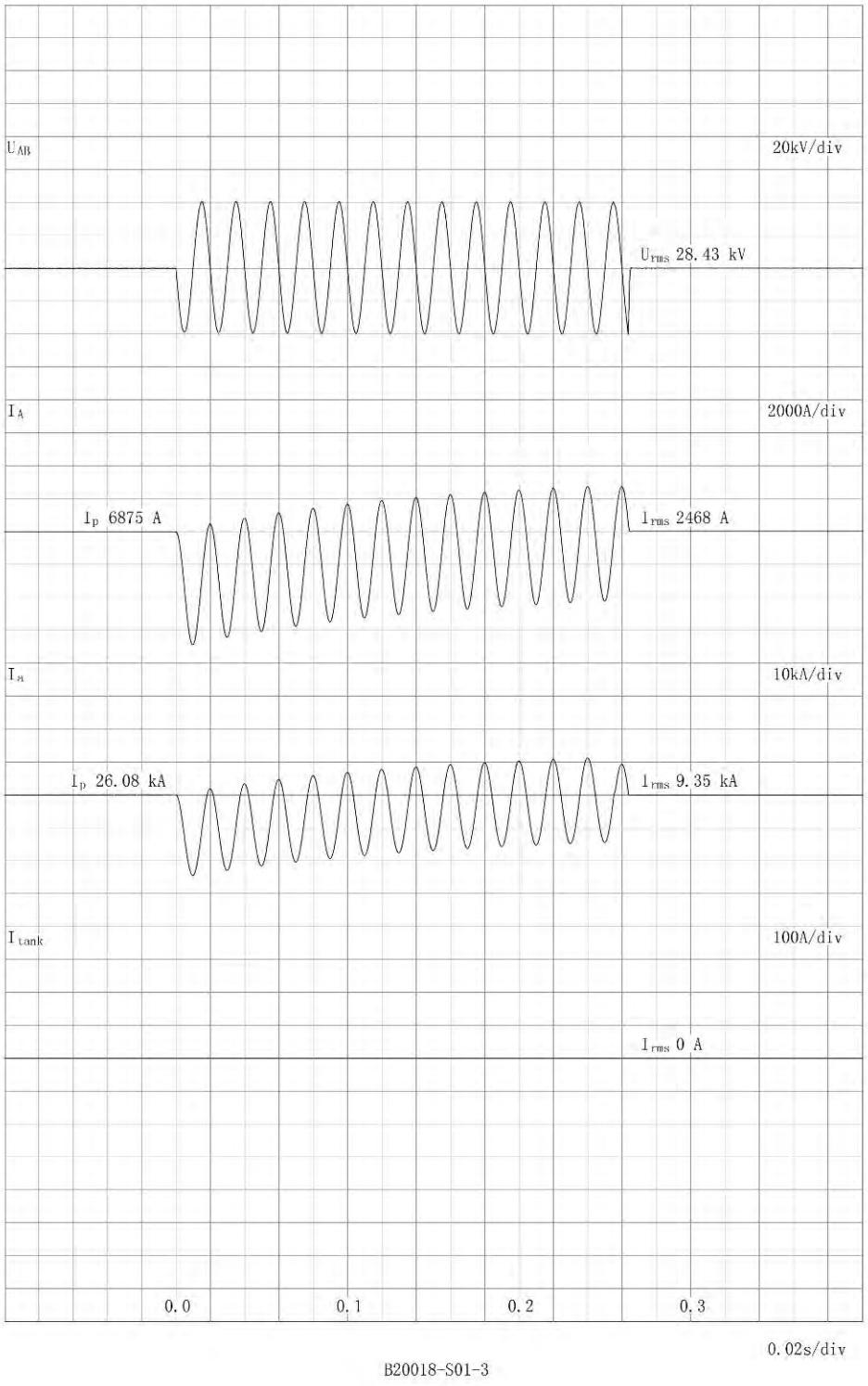


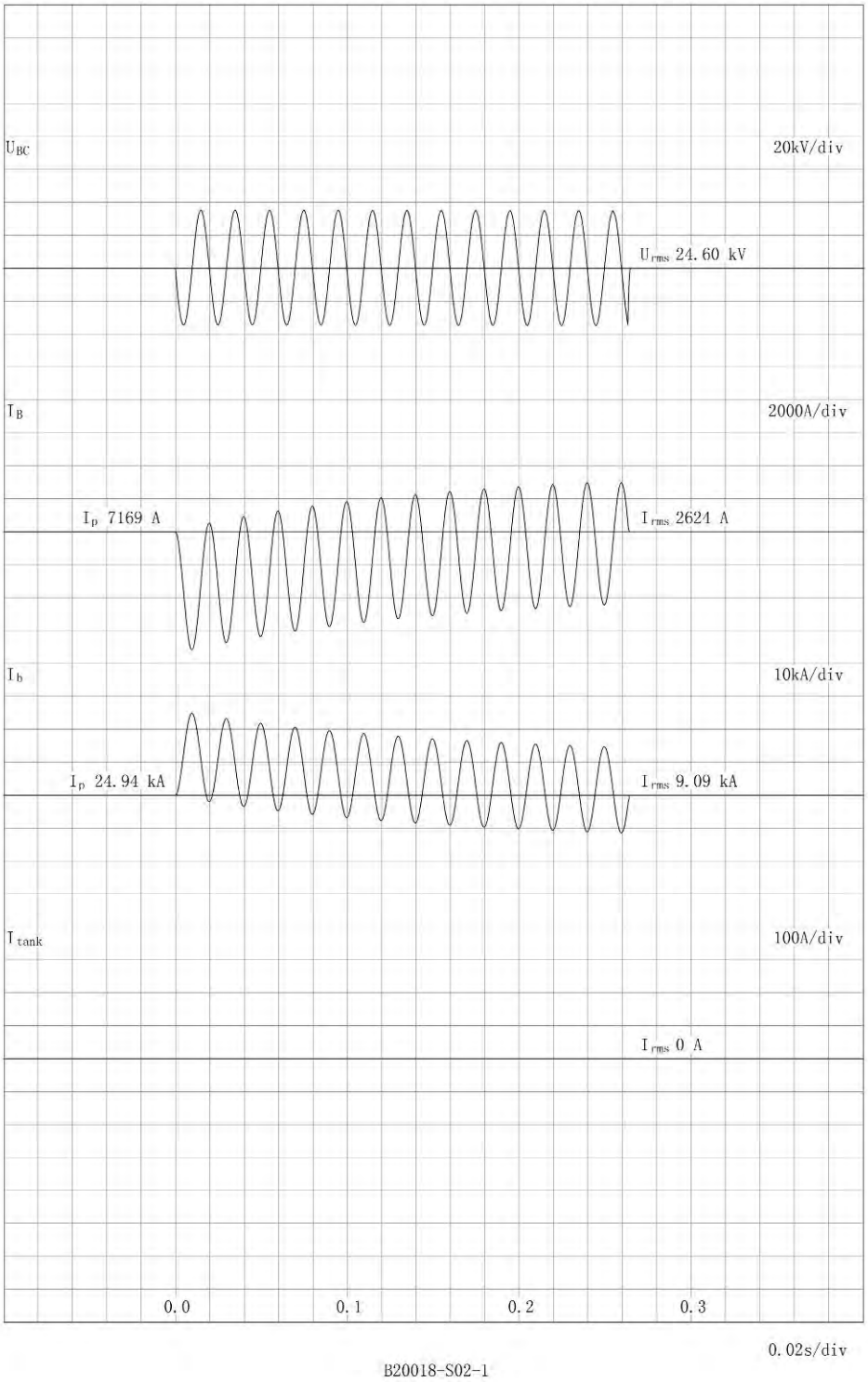
Phase C Tap 7 to tap 6

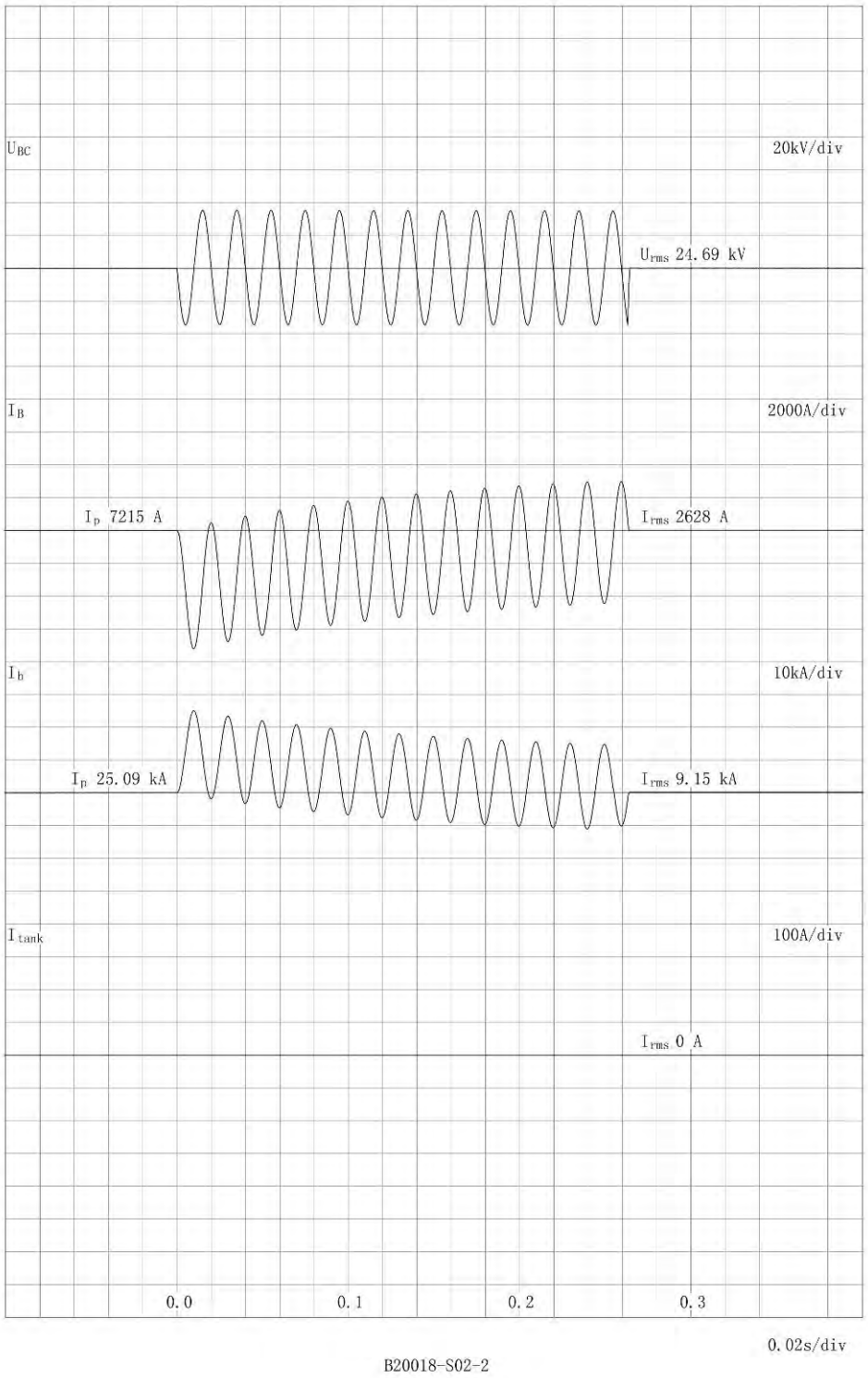

U_{AB}
20kV/div
U_{rms} 28.38 kV
I_A
2000A/div
I_p 6710 A
I_{rms} 2427 A
I_n
10kA/div
I_p 25.12 kA
I_{rms} 9.18 kA
I_{tank}
100A/div
I_{rms} 0 A
0.0
0.1
0.2
0.3
0.02s/div

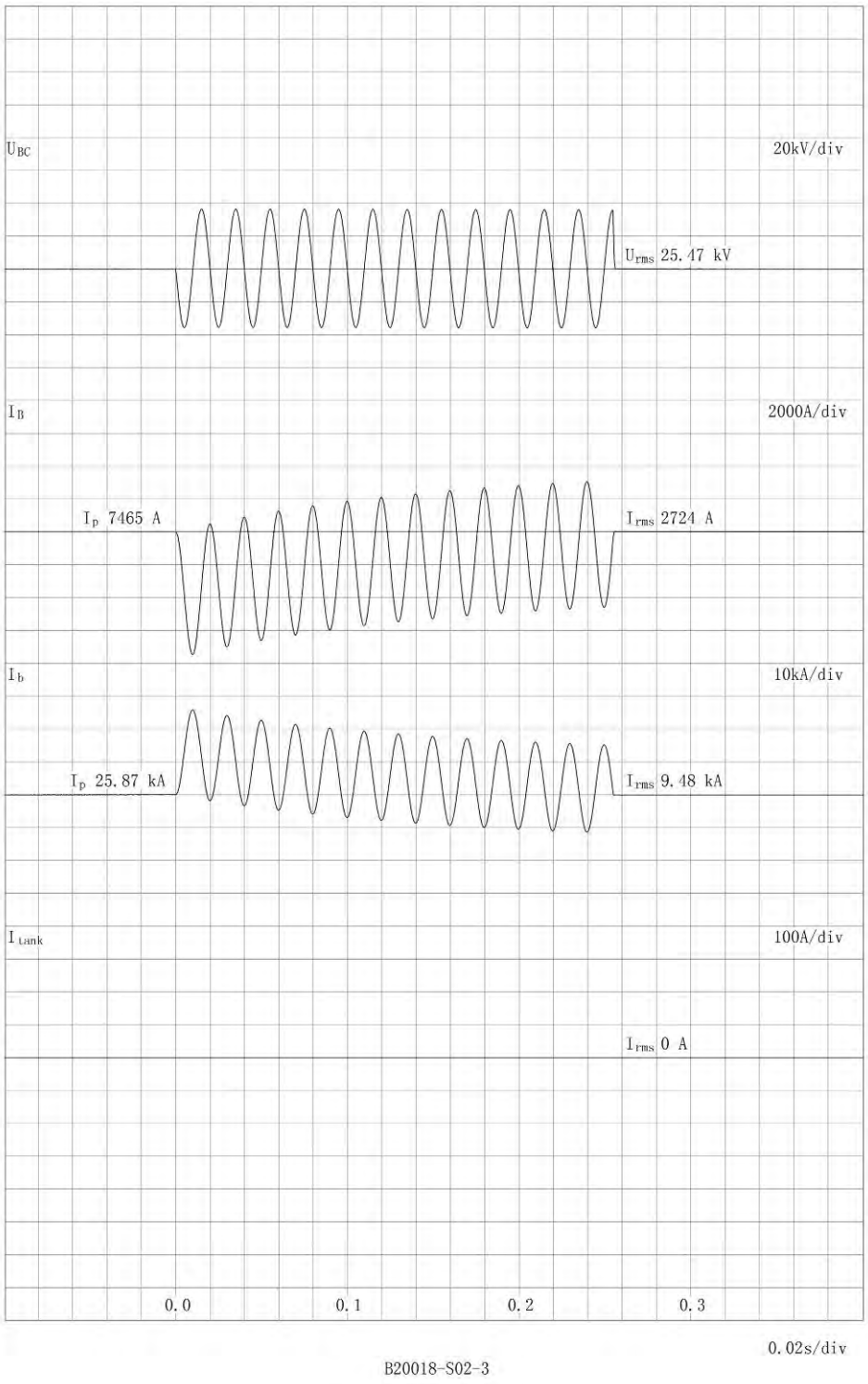
B20018-S01-1

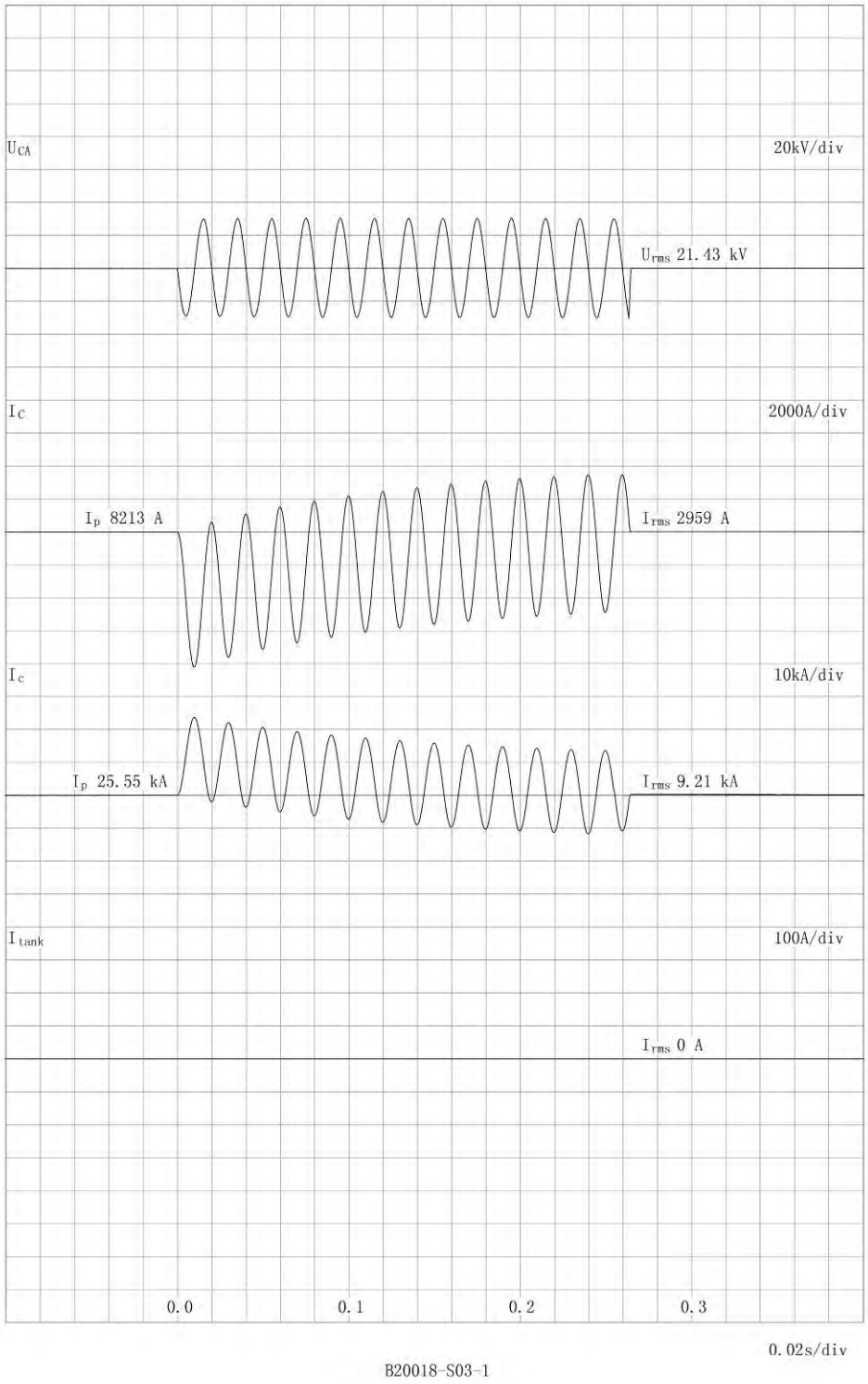

U_{AB}
20kV/div
U_{rms} 28.35 kV
I_A
2000A/div
I_p 6765 A
I_{rms} 2448 A
I_a
10kA/div
I_p 25.70 kA
I_{rms} 9.33 kA
I_{tank}
100A/div
I_{rms} 0 A
0.0
0.1
0.2
0.3
0.02s/div
B20018-S01-2


U_{AB}
20kV/div
U_{rms} 28.43 kV
I_A
2000A/div
I_p 6875 A
I_{rms} 2468 A
I_m
10kA/div
I_p 26.08 kA
I_{rms} 9.35 kA
I_{tank}
100A/div
I_{rms} 0 A
0.0
0.1
0.2
0.3
0.02s/div
B20018-S01-3

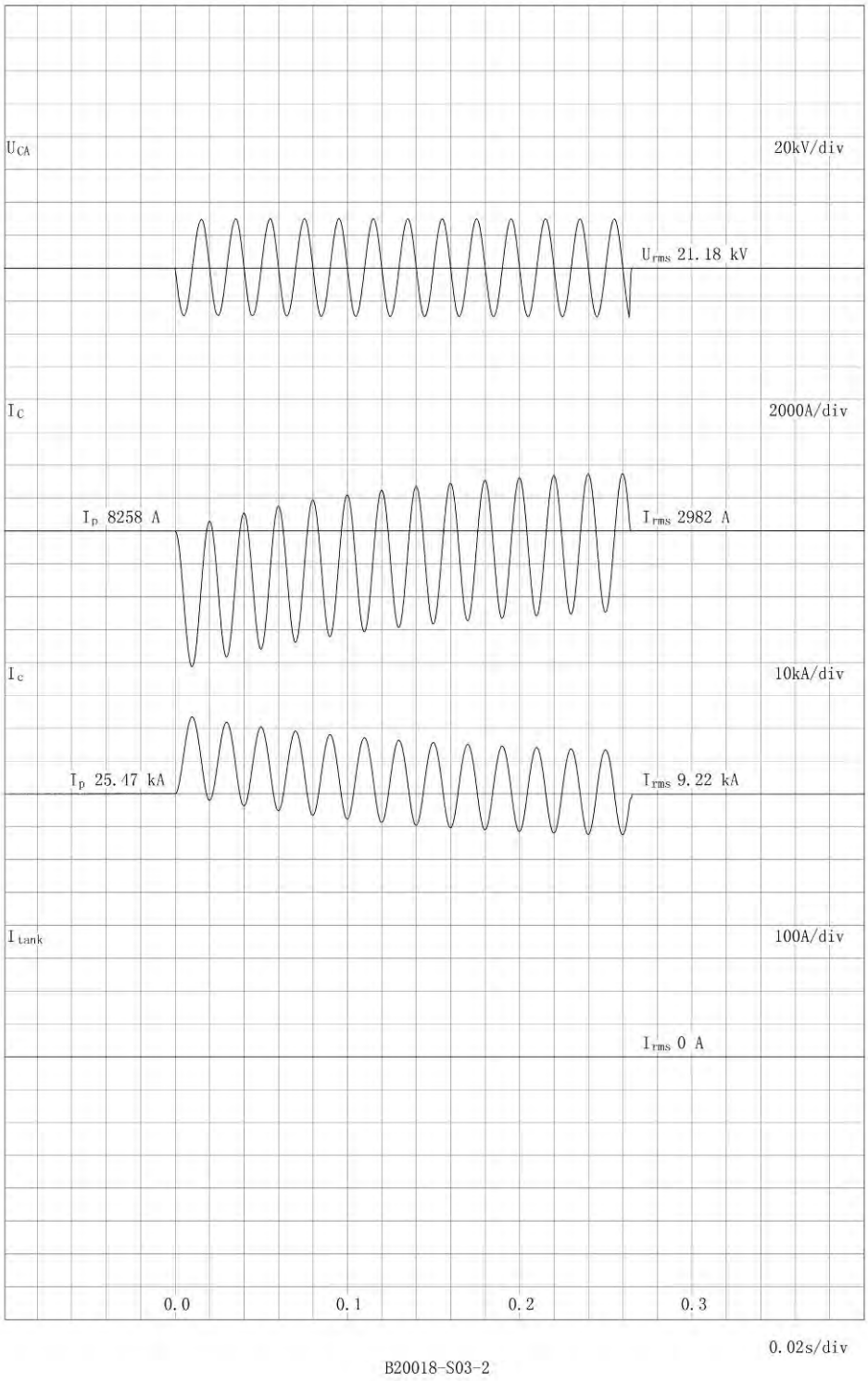

U_{BC}
20kV/div
U_{rms} 24.60 kV
I_B
2000A/div
I_p 7169 A
I_{rms} 2624 A
I_b
10kA/div
I_p 24.94 kA
I_{rms} 9.09 kA
I_{tank}
100A/div
I_{rms} 0 A
0.0
0.1
0.2
0.3
0.02s/div
B20018-S02-1

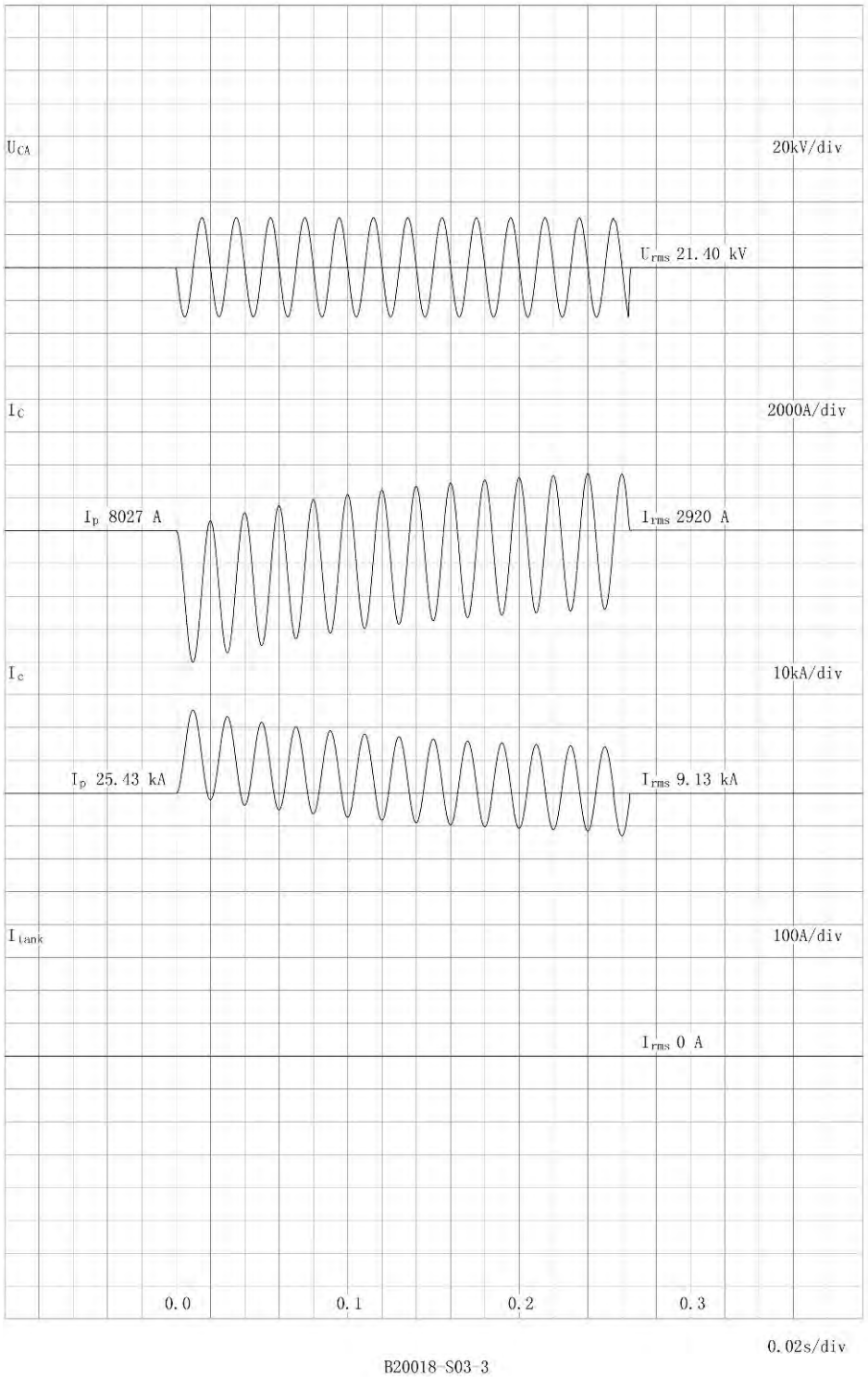

U_{BC}
20kV/div
U_{rms} 24.69 kV
I_B
2000A/div
I_p 7215 A
I_{rms} 2628 A
I_b
10kA/div
I_p 25.09 kA
I_{rms} 9.15 kA
I_{tank}
100A/div
I_{rms} 0 A
0.0
0.1
0.2
0.3
0.02s/div
B20018-S02-2


U_{BC}
20kV/div
U_{rms} 25.47 kV
I_B
2000A/div
I_p 7465 A
I_{rms} 2724 A
I_b
10kA/div
I_p 25.87 kA
I_{rms} 9.48 kA
I_{tank}
100A/div
I_{rms} 0 A
0.0
0.1
0.2
0.3
0.02s/div
B20018-S02-3

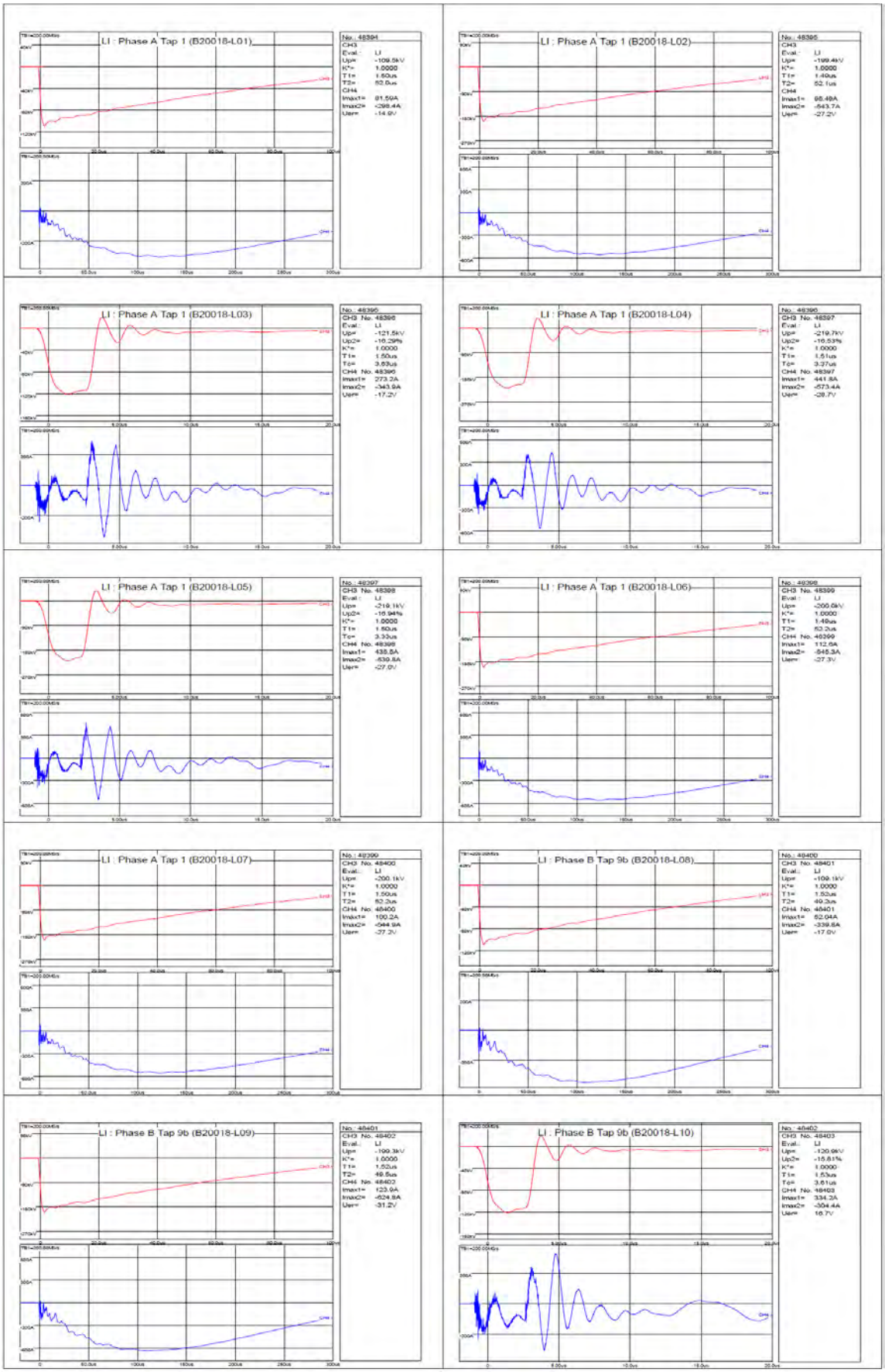

U_{CA}
20kV/div
U_{rms} 21.43 kV
I_C
2000A/div
I_p 8213 A
I_{rms} 2959 A
I_c
10kA/div
I_p 25.55 kA
I_{rms} 9.21 kA
I_{tank}
100A/div
I_{rms} 0 A
0.0
0.1
0.2
0.3
0.02s/div

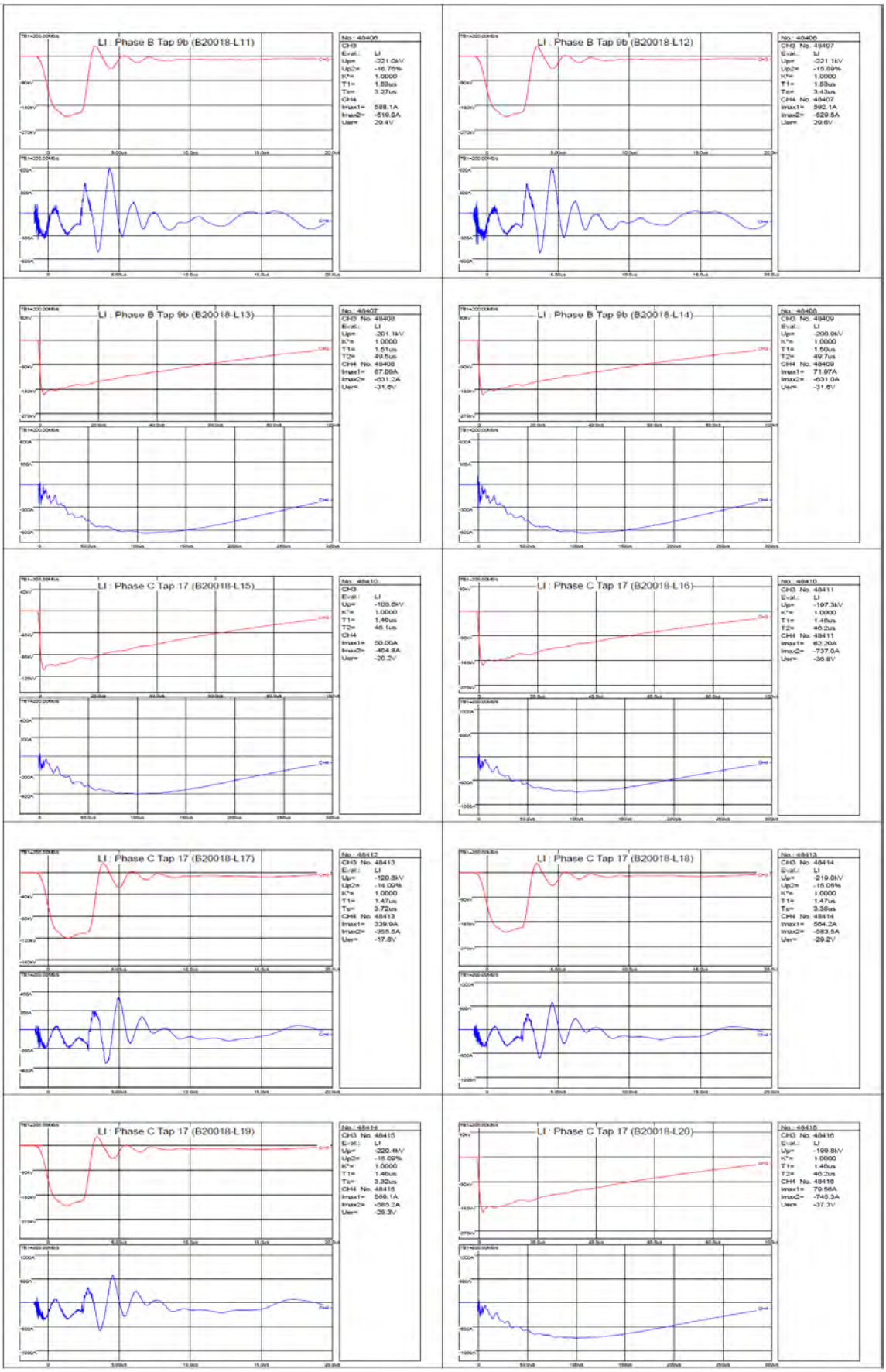
B20018-S03-1

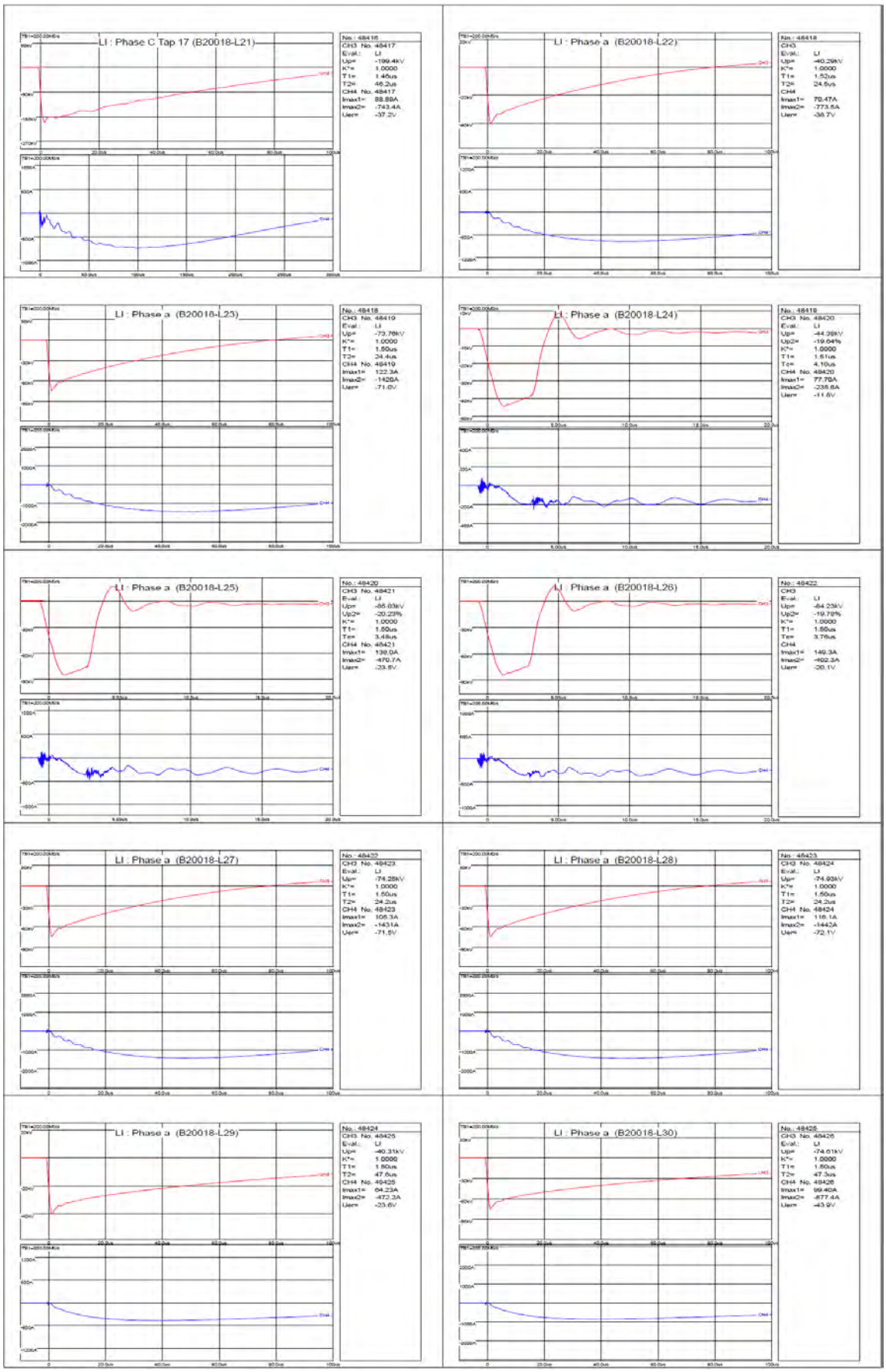

U_{CA}
20kV/div
U_{rms} 21.18 kV
I_C
2000A/div
I_p 8258 A
I_{rms} 2982 A
I_c
10kA/div
I_p 25.47 kA
I_{rms} 9.22 kA
I_{tank}
100A/div
I_{rms} 0 A
0.0
0.1
0.2
0.3
0.02s/div
B20018-S03-2

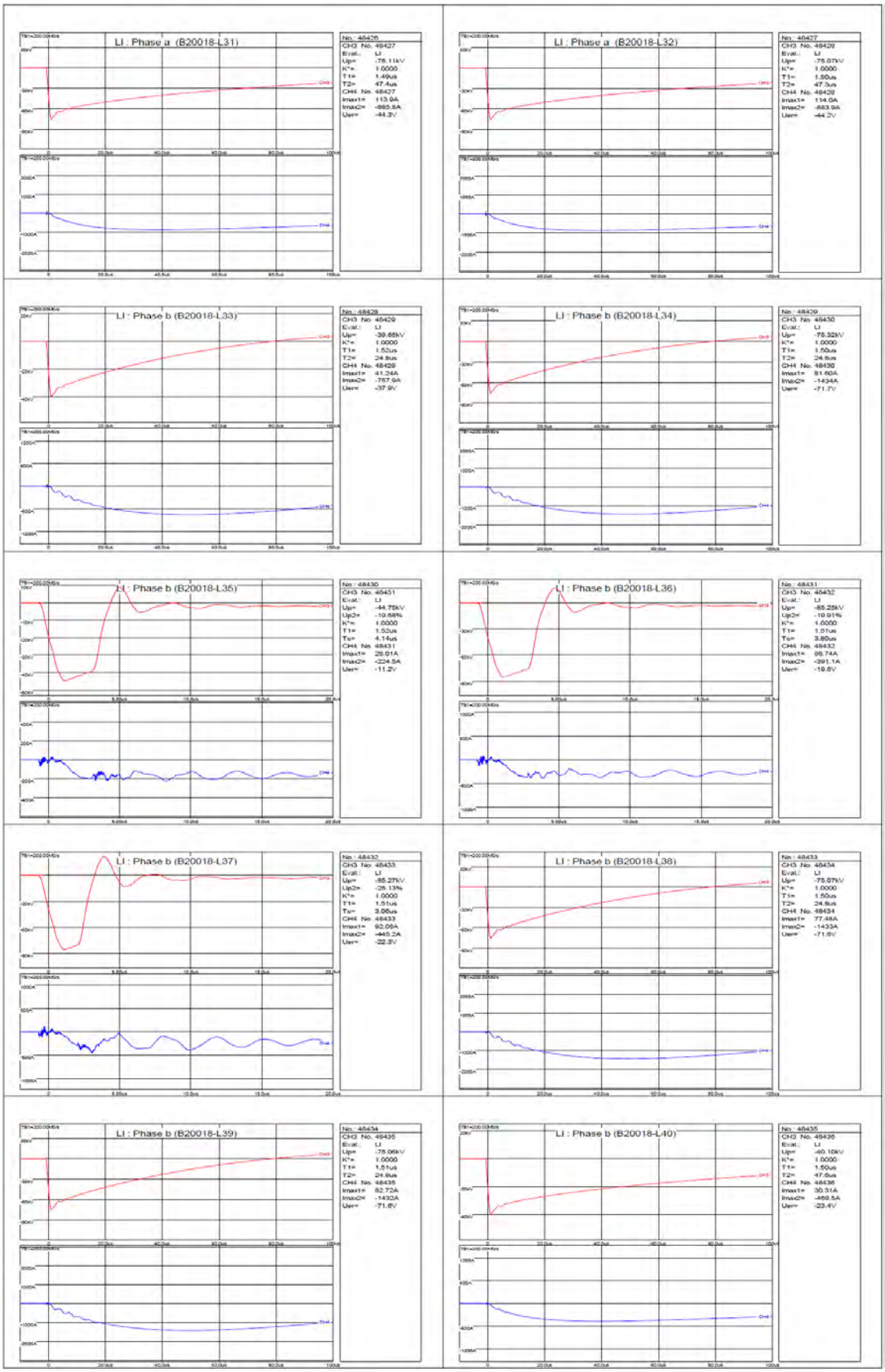

U_{CA}
20kV/div
U_{rms} 21.40 kV
I_C
2000A/div
I_p 8027 A
I_{rms} 2920 A
I_c
10kA/div
I_p 25.43 kA
I_{rms} 9.13 kA
I_{tank}
100A/div
I_{rms} 0 A
0.0
0.1
0.2
0.3
0.02s/div

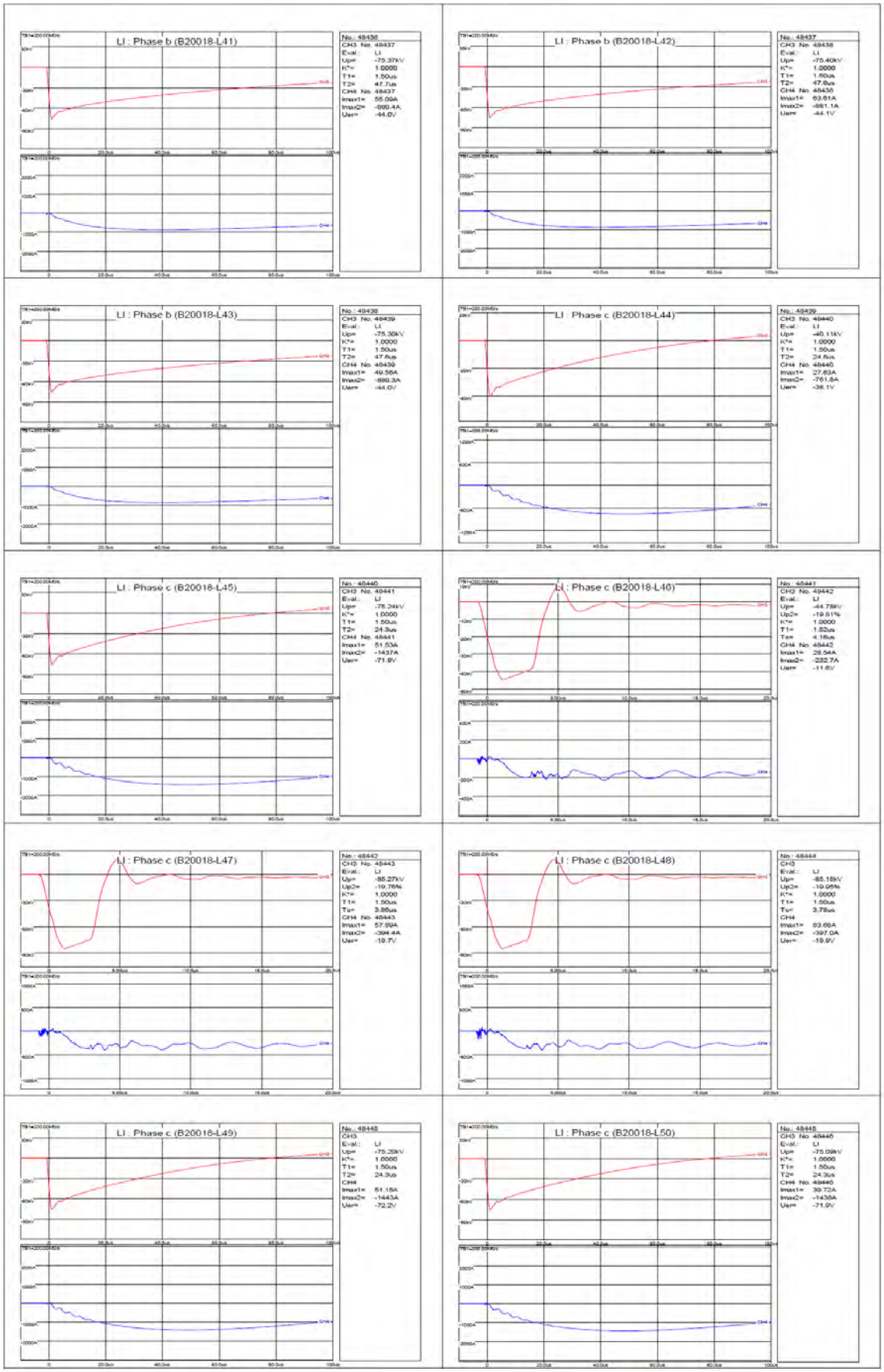
B20018-S03-3

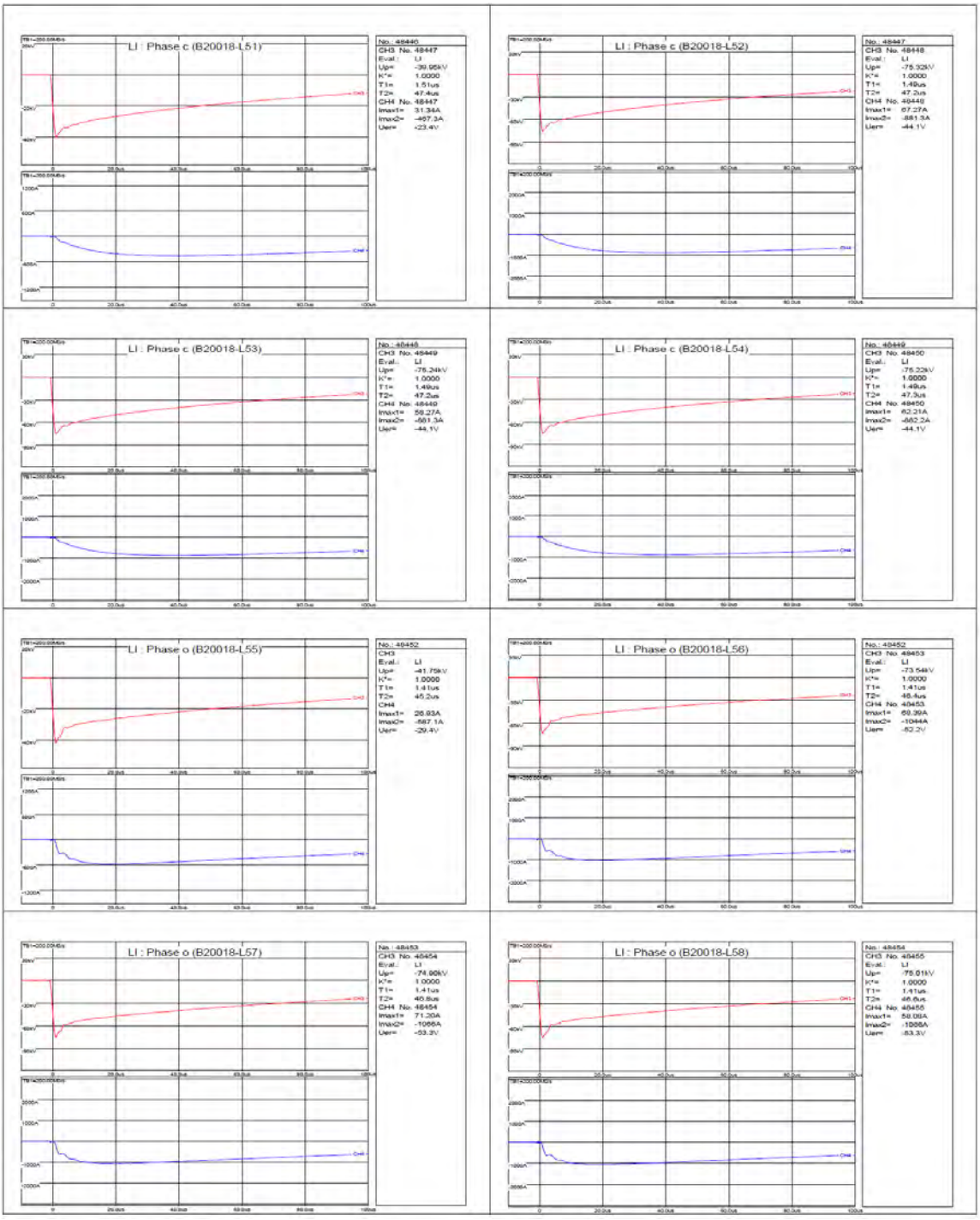

LI : Phase A Tap 1 (B20018-L01)
LI : Phase A Tap 1 (B20018-L02)
LI : Phase A Tap 1 (B20018-L03)
LI : Phase A Tap 1 (B20018-L04)
LI : Phase A Tap 1 (B20018-L05)
LI : Phase A Tap 1 (B20018-L06)
LI : Phase A Tap 1 (B20018-L07)
LI : Phase B Tap 9b (B20018-L08)
LI : Phase B Tap 9b (B20018-L09)
LI : Phase B Tap 9b (B20018-L10)

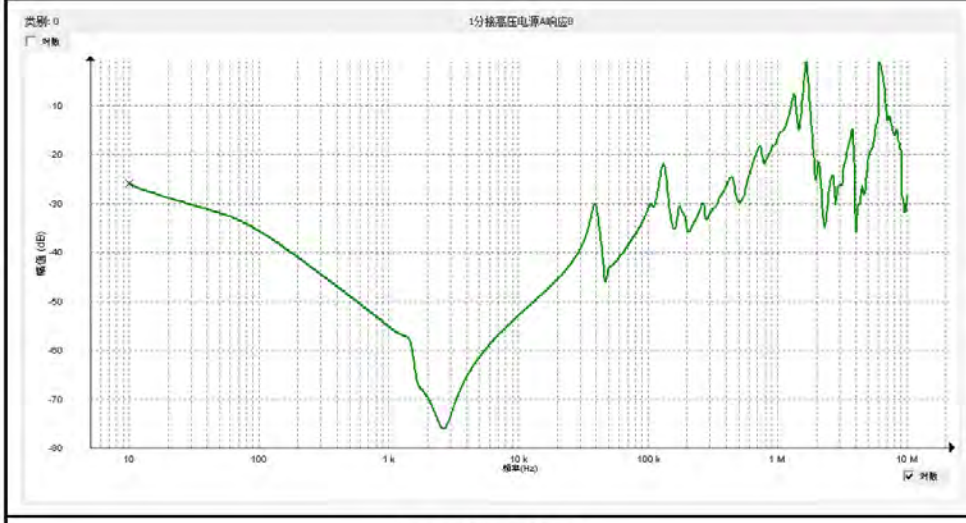

LI : Phase B Tap 9b (B20018-L11)
LI : Phase B Tap 9b (B20018-L12)
LI : Phase B Tap 9b (B20018-L13)
LI : Phase B Tap 9b (B20018-L14)
LI : Phase C Tap 17 (B20018-L15)
LI : Phase C Tap 17 (B20018-L16)
LI : Phase C Tap 17 (B20018-L17)
LI : Phase C Tap 17 (B20018-L18)
LI : Phase C Tap 17 (B20018-L19)
LI : Phase C Tap 17 (B20018-L20)


LI : Phase C Tap 17 (B20018-L21)
LI : Phase a (B20018-L22)
LI : Phase a (B20018-L23)
LI : Phase a (B20018-L24)
LI : Phase a (B20018-L25)
LI : Phase a (B20018-L26)
LI : Phase a (B20018-L27)
LI : Phase a (B20018-L28)
LI : Phase a (B20018-L29)
LI : Phase a (B20018-L30)

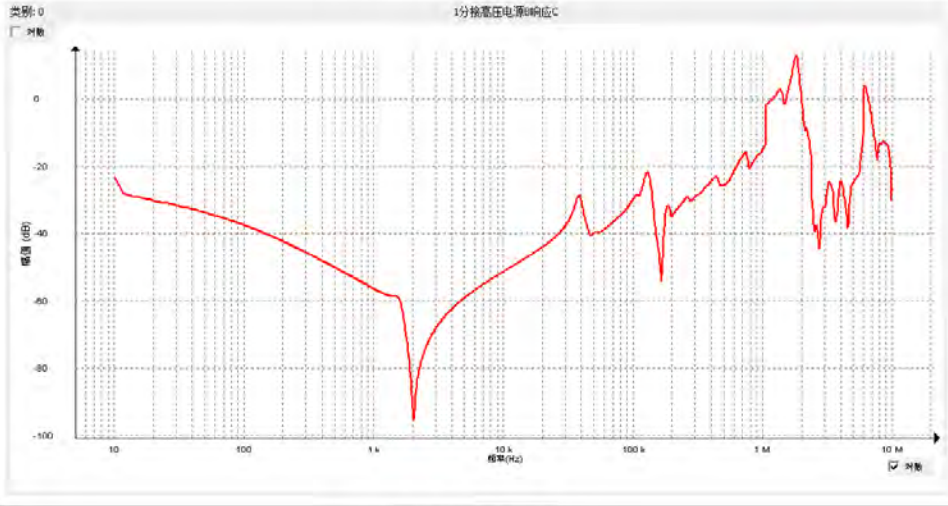

LI : Phase a (B20018-L31)
LI : Phase a (B20018-L32)
LI : Phase b (B20018-L33)
LI : Phase b (B20018-L34)
LI : Phase b (B20018-L35)
LI : Phase b (B20018-L36)
LI : Phase b (B20018-L37)
LI : Phase b (B20018-L38)
LI : Phase b (B20018-L39)
LI : Phase b (B20018-L40)


LI : Phase b (B20018-L41)
LI : Phase b (B20018-L42)
LI : Phase b (B20018-L43)
LI : Phase c (B20018-L44)
LI : Phase c (B20018-L45)
LI : Phase c (B20018-L46)
LI : Phase c (B20018-L47)
LI : Phase c (B20018-L48)
LI : Phase c (B20018-L49)
LI : Phase c (B20018-L50)

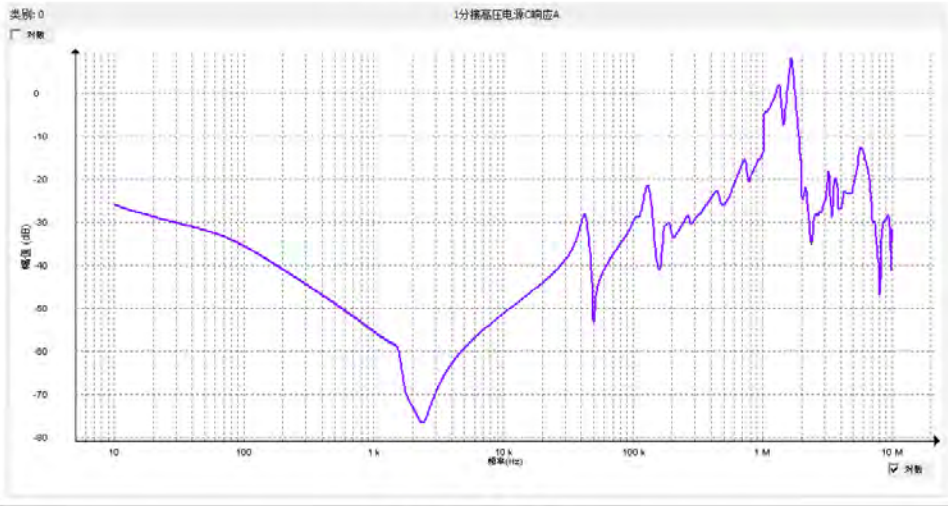

LI : Phase c (B20018-L51)
LI : Phase c (B20018-L52)
LI : Phase c (B20018-L53)
LI : Phase c (B20018-L54)
LI : Phase o (B20018-L55)
LI : Phase o (B20018-L56)
LI : Phase o (B20018-L57)
LI : Phase o (B20018-L58)



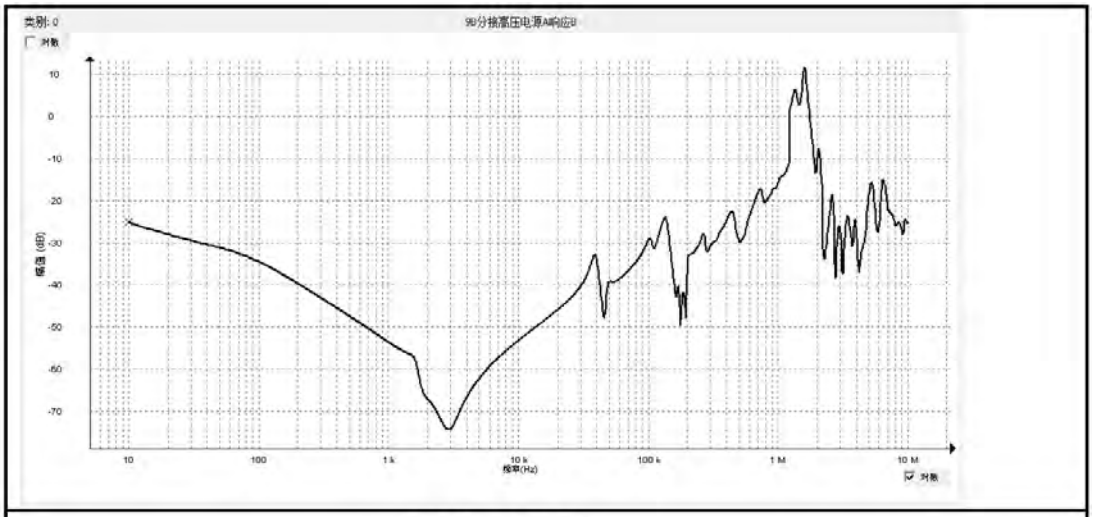
B20018-FRA-01



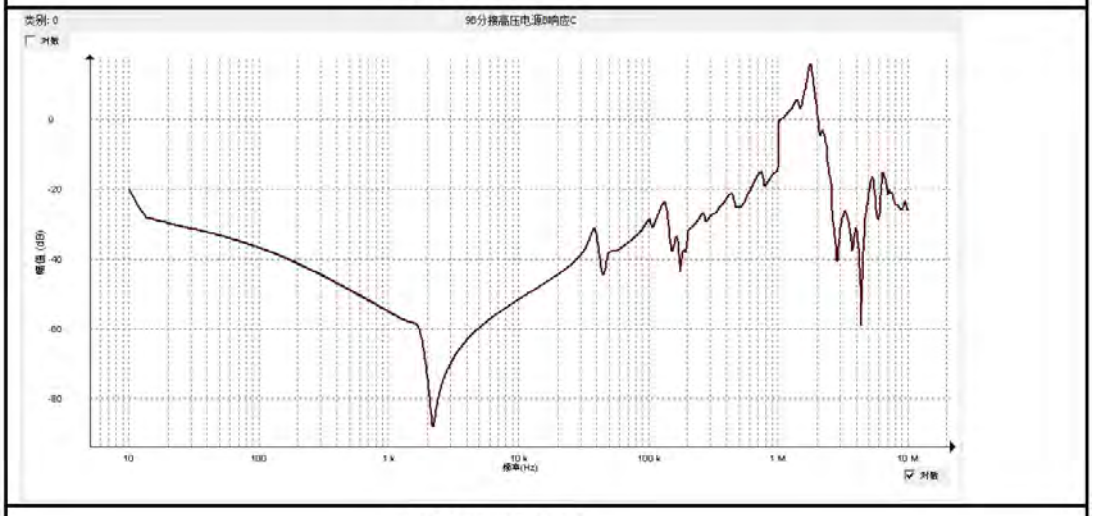
B20018-FRA-02



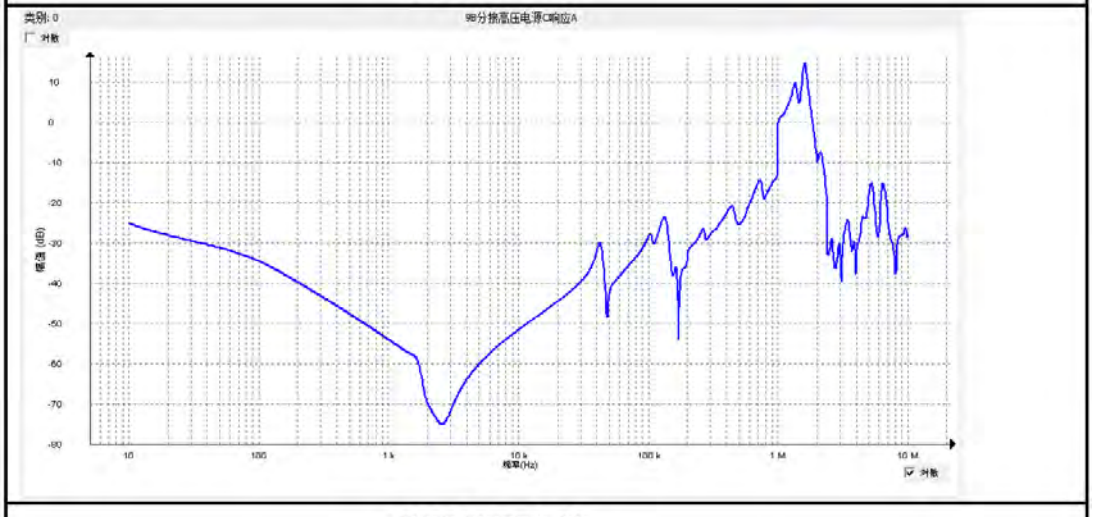
B20018-FRA-03



B20018-FRA-04



B20018-FRA-05



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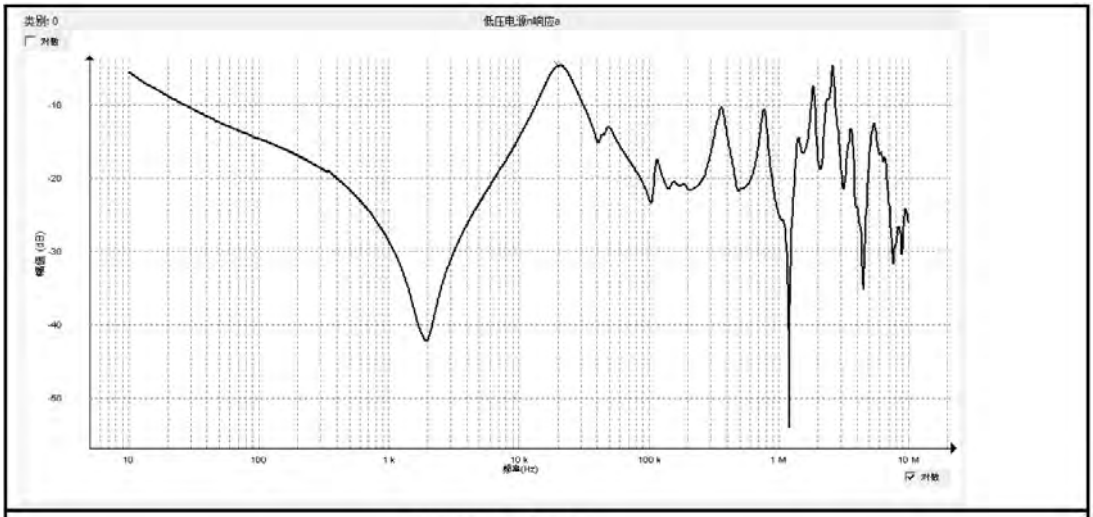

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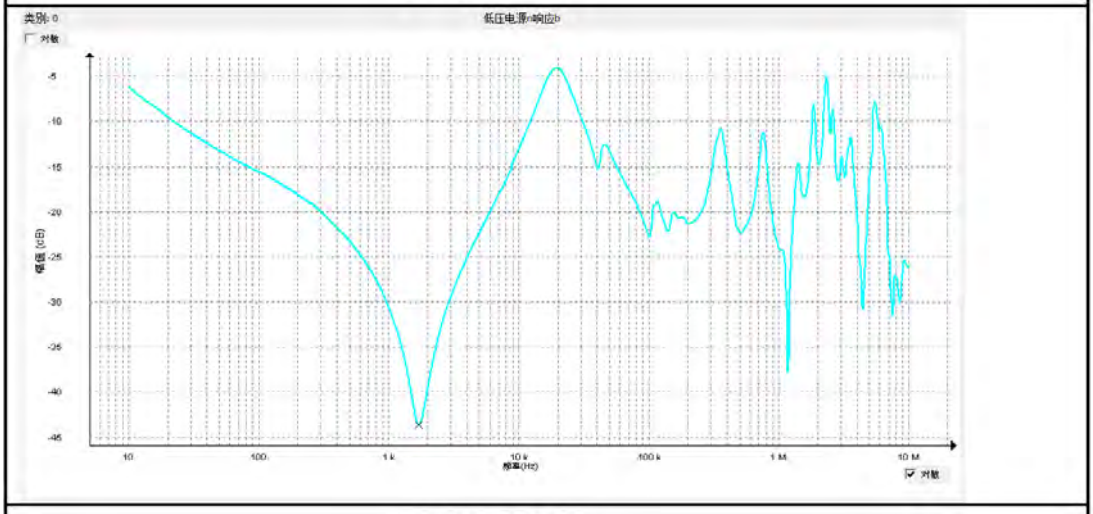

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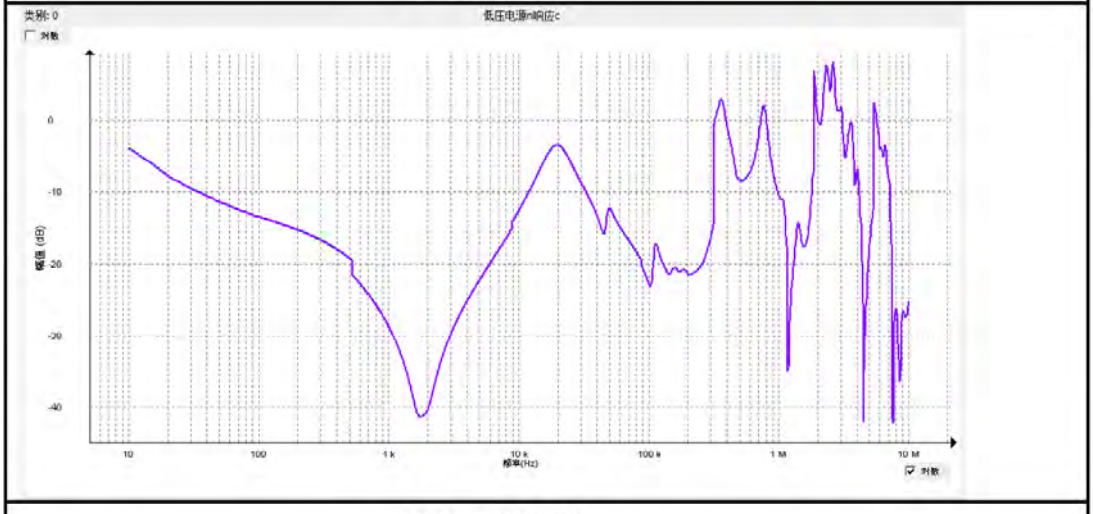

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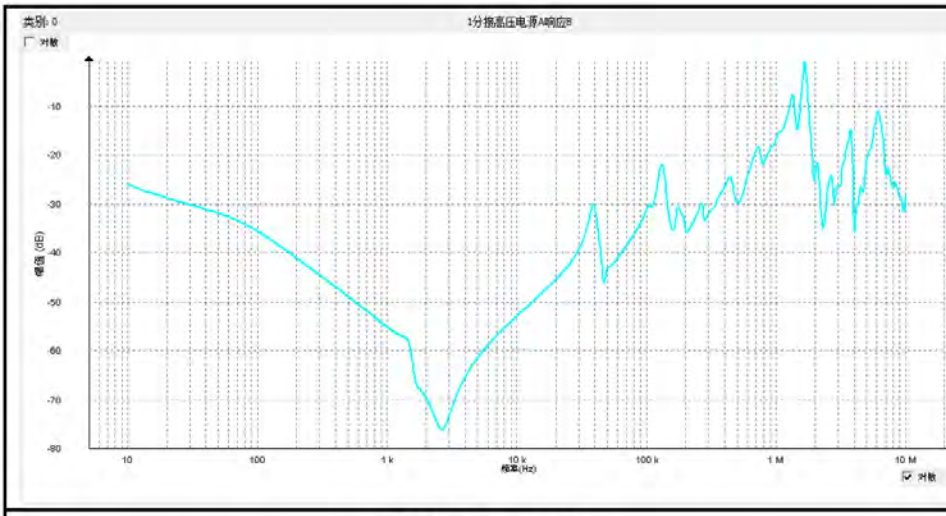

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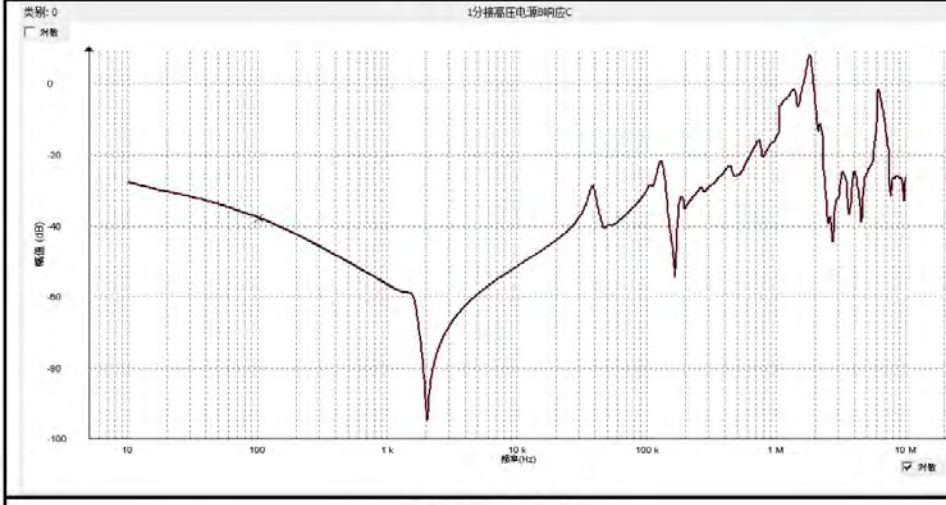

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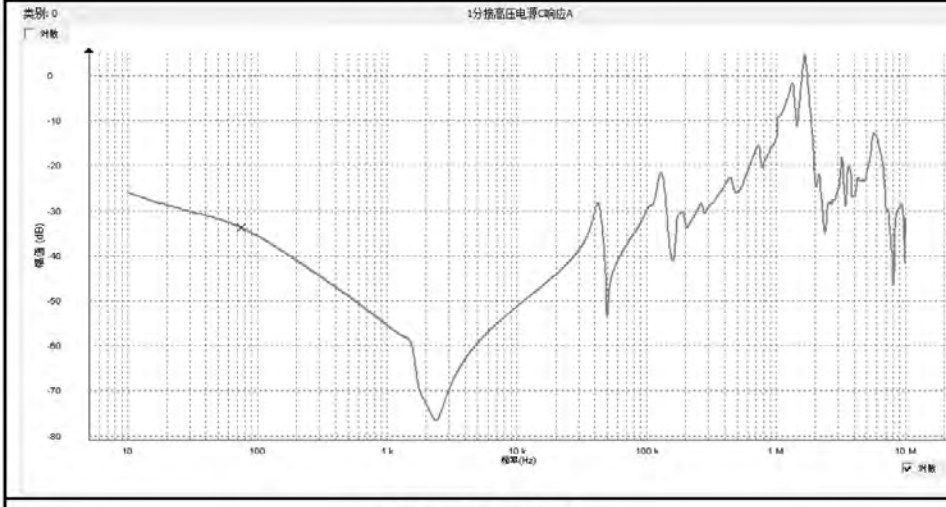

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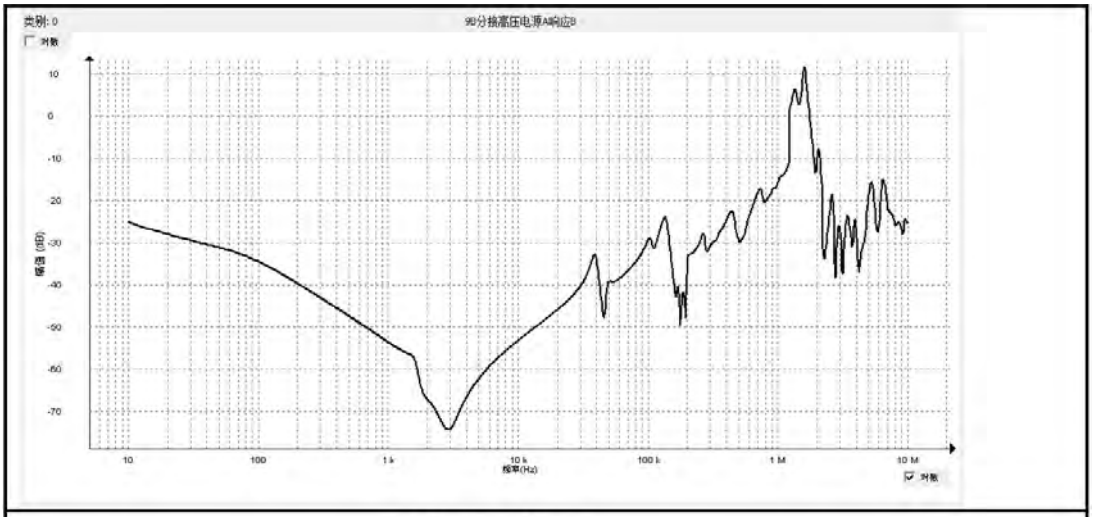

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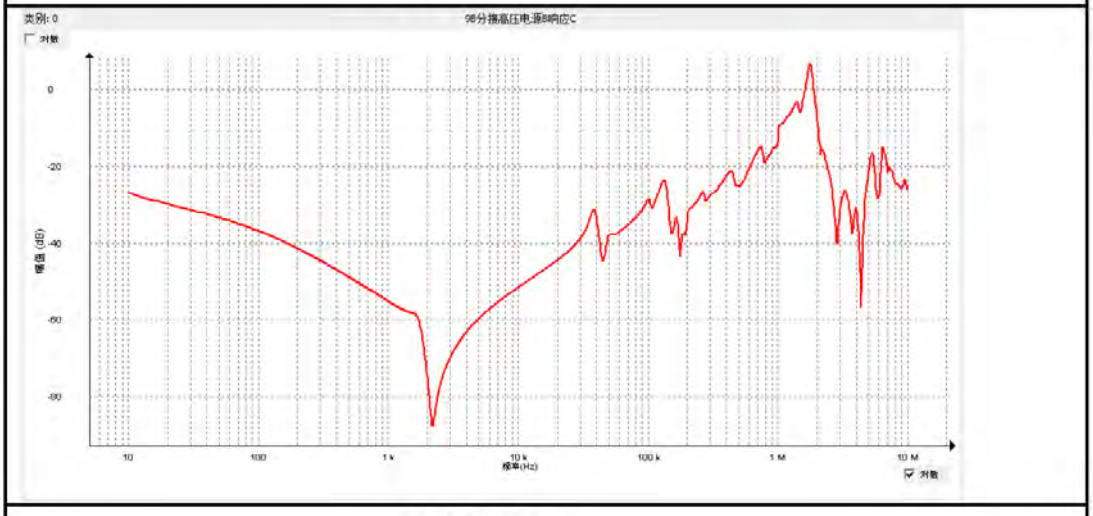

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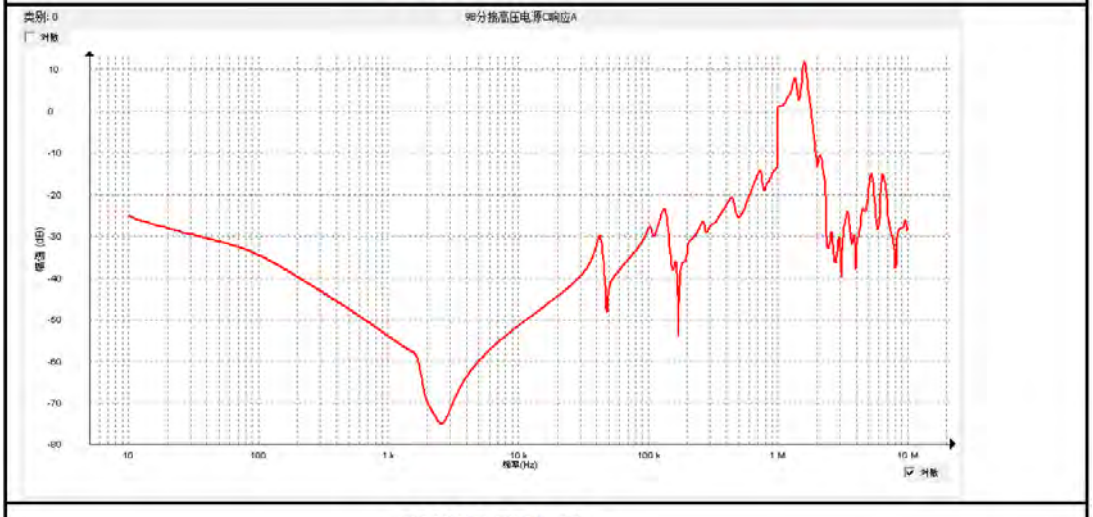

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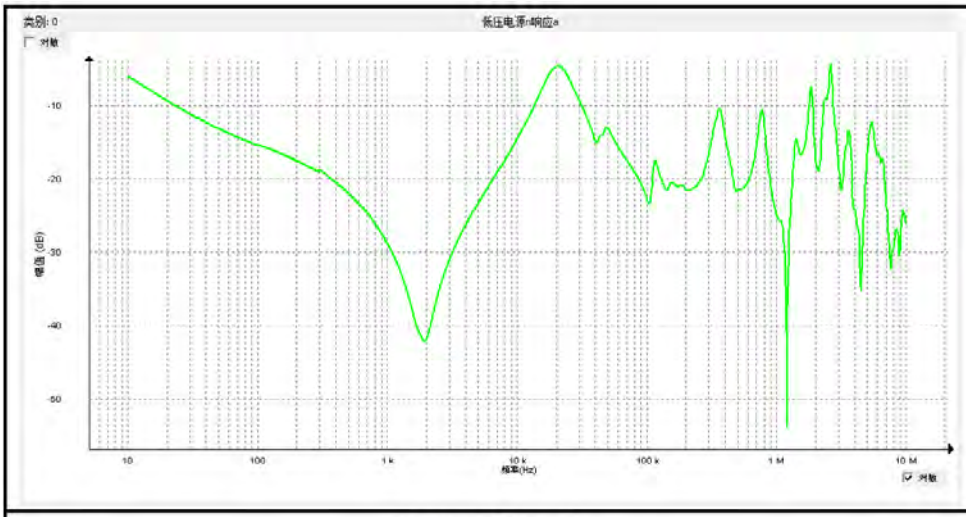

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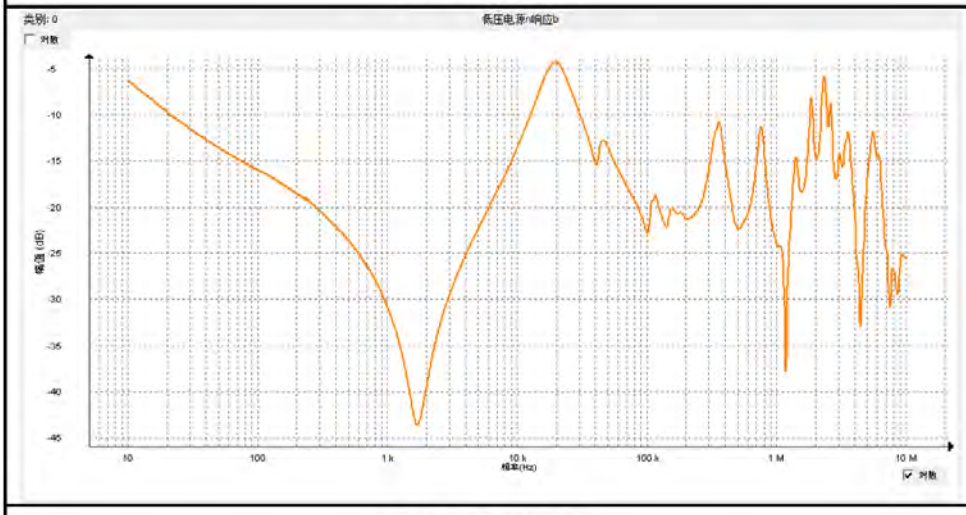

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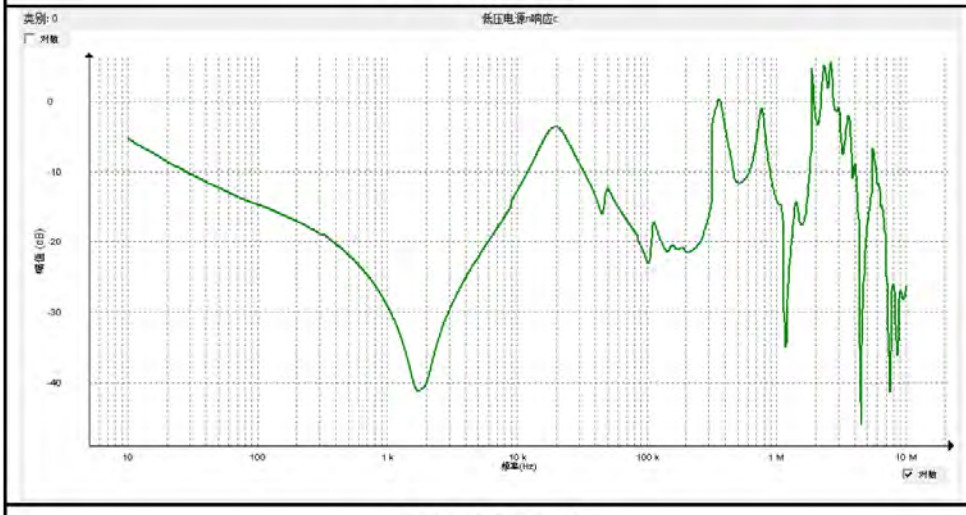

B20018-FRA-18

Photo no.: P001

Photo no.: P002

Photo no.: P003

Photo no.: P004

Photo no.: P005

Photo no.: P006

Photo no.: P007

Photo no.: P008

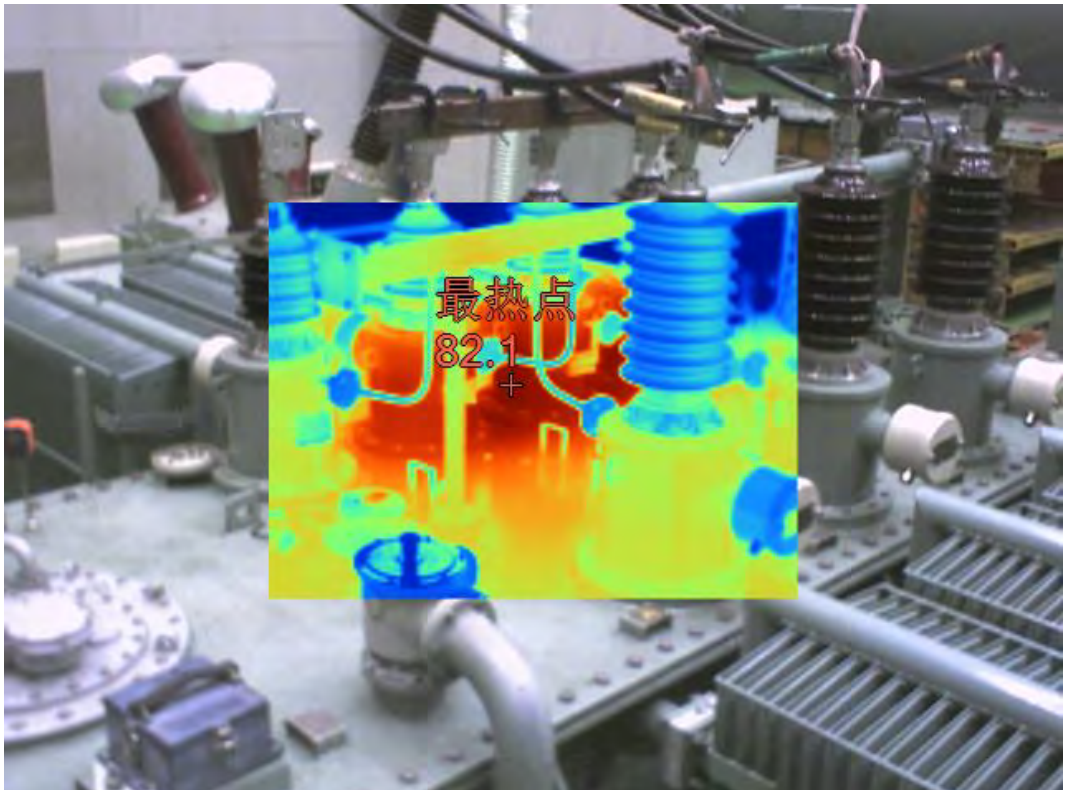

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Photo no.: P010

Photo no.: P011

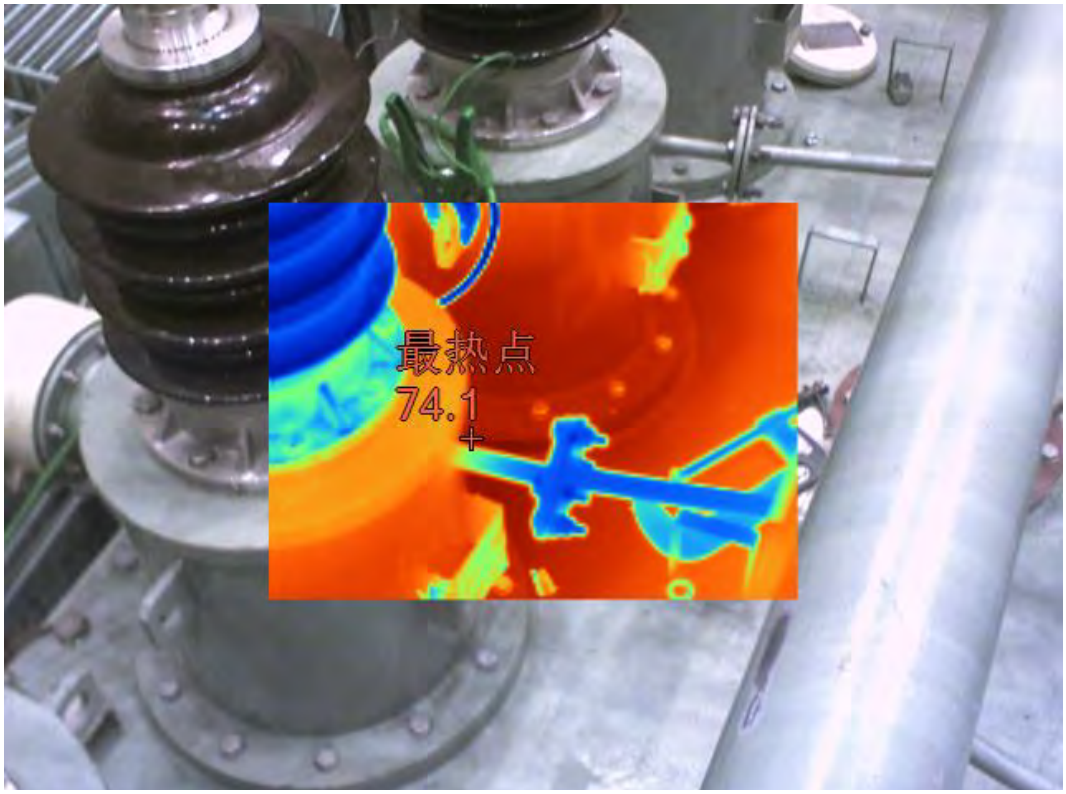

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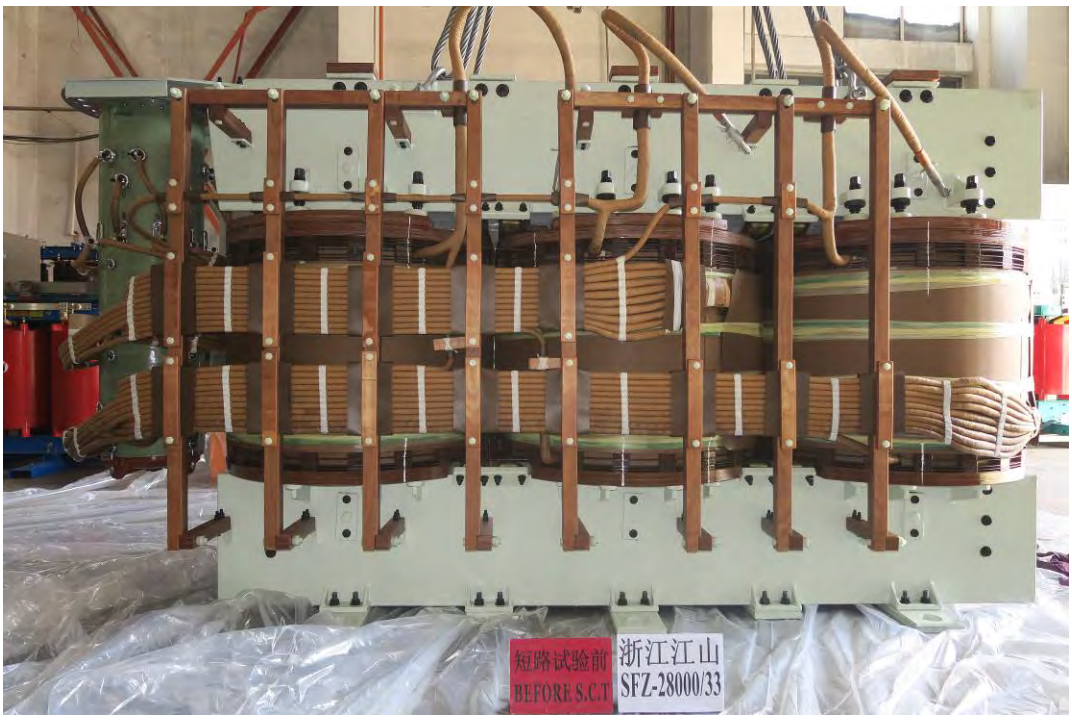
Photo no.: P014



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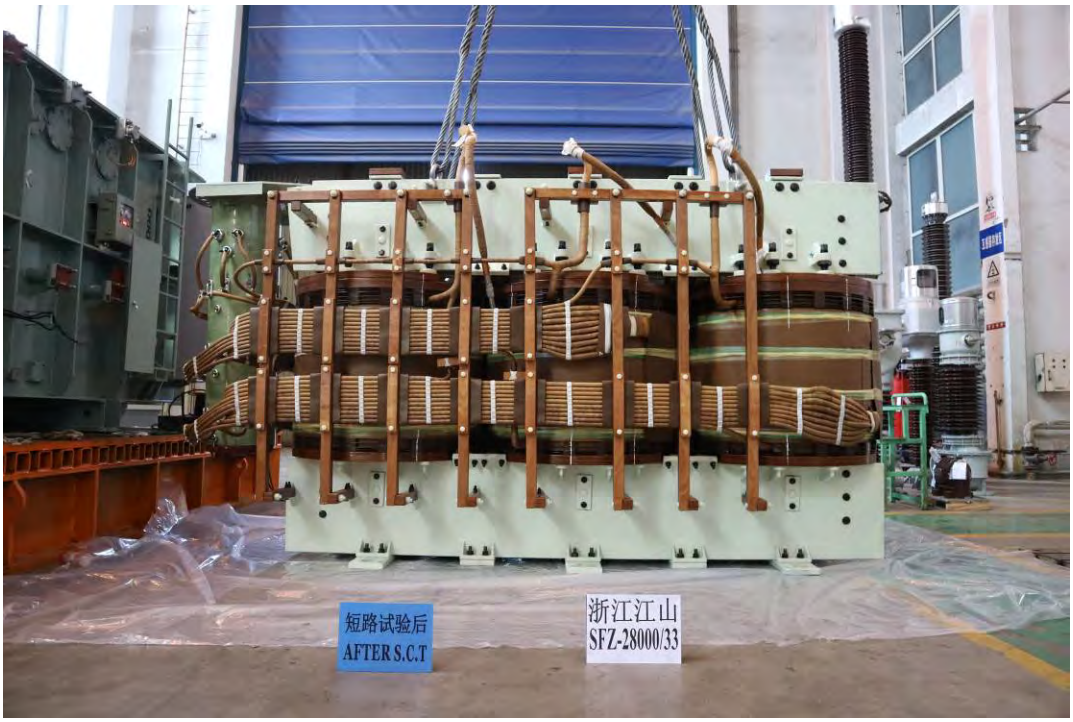

Photo no.: P017

Photo no.: P018

Photo no.: P019

Photo no.: P020

Photo no.: P021

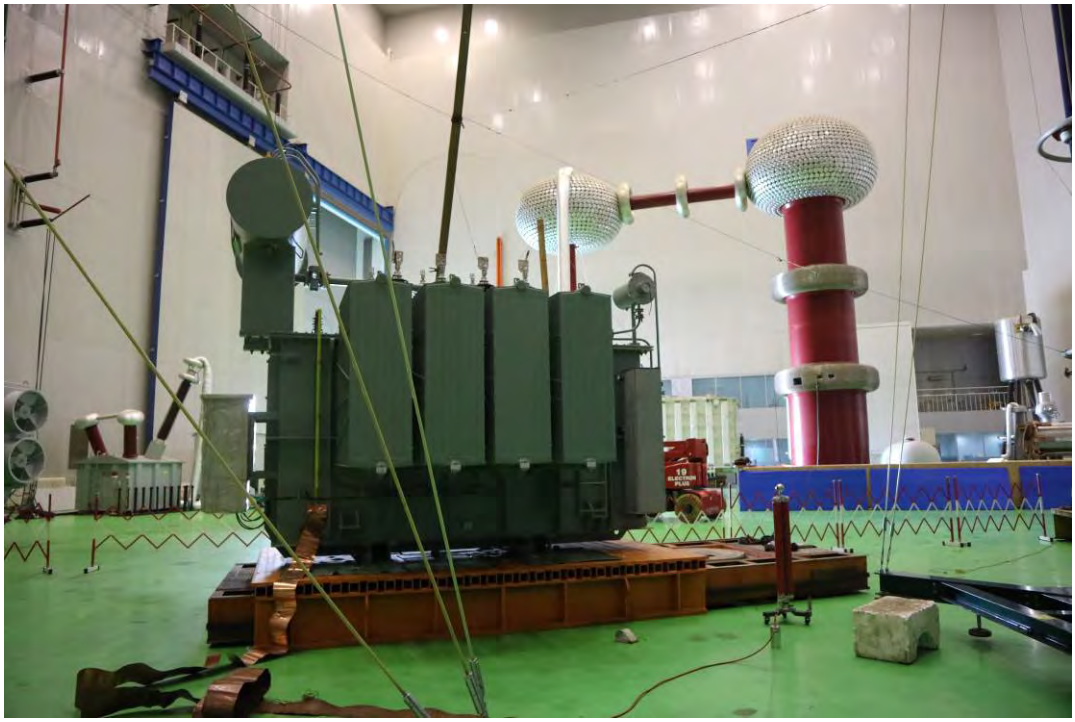

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Photo no.: P023

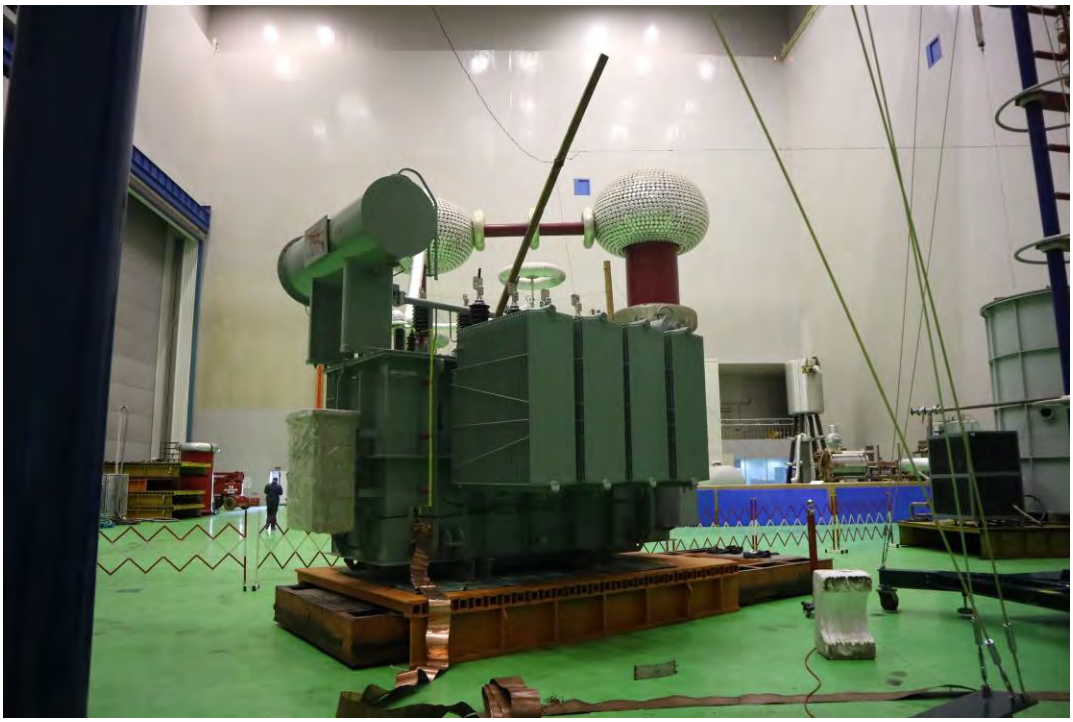

Photo no.: P024

Photo no.: P025

Photo no.: P026