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TECHNICAL SPECIFICATION

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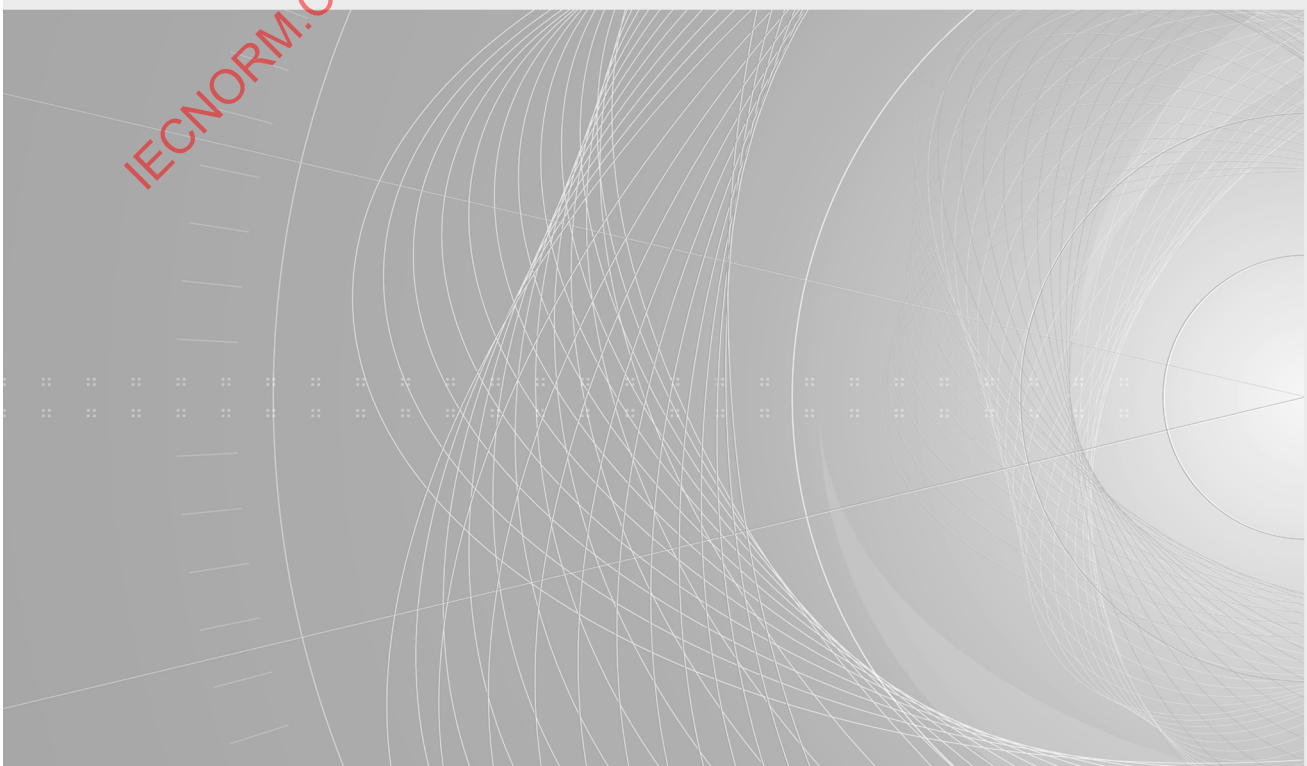
UHV AC transmission systems – Part 302: Commissioning



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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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UHV AC transmission systems – Part 302: Commissioning

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CONTENTS

FOREWORD 5
INTRODUCTION 7
1 Scope 8
2 Normative references 8
3 Terms and definitions 8
4 General 9
4.1 Requirements 9
4.2 Main purpose 9
4.3 General structure of commissioning 10
4.4 Scope of application 10
4.5 Technical preparation of system commissioning 10
5 Pre-commissioning 11
5.1 General 11
5.2 Combined test 11
5.2.1 General 11
5.2.2 Protection and control system test 11
5.2.3 Instrument transformer test 12
5.2.4 Switchgear and transformer test 12
5.2.5 AC and DC power supply system test 13
5.3 Communication system test 13
6 System commissioning 13
6.1 General 13
6.2 Test requirements 14
6.2.1 General 14
6.2.2 Energizing test of no-load UHV power transformer 14
6.2.3 Energizing test of tertiary connected reactor 14
6.2.4 Energizing test of tertiary connected capacitor 15
6.2.5 Energizing test of UHV busbar shunt reactor 16
6.2.6 Energizing test of UHV busbar 16
6.2.7 Energizing test of no-load UHV transmission line 17
6.2.8 Loop closing (interconnecting)/opening (splitting) test 18
7 Measurement in system commissioning 19
7.1 General 19
7.2 Measurement requirements 19
7.2.1 General 19
7.2.2 Transient voltage and current measurement 19
7.2.3 Electric quantity measurement 20
7.2.4 Relay protection measurement 20
7.2.5 Harmonic measurement 20
7.2.6 Sound level measurement of power transformer/shunt reactor 20
7.2.7 Vibration measurement 21
7.2.8 DGA of power transformer/shunt reactor 21
7.2.9 Temperature measurement 21
7.2.10 Power frequency electric and magnetic field measurement of substation and transmission line 22
7.2.11 Audible noise measurement of substation and transmission line 22

7.2.12 Radio interference measurement of transmission line 22
7.2.13 Partial discharge monitoring in GIS/power transformer 22
Annex A (informative) Commissioning experiences in China 23
A.1 General 23
A.2 Overview 23
A.3 Regulations 23
A.4 Pre-commissioning 23
A.5 System commissioning 26
A.5.1 General 26
A.5.2 Technical preparations 26
A.5.3 Confirmation on preconditions for on-site commissioning 27
A.5.4 System commissioning tests 27
A.6 Measurement in system commissioning 35
A.6.1 General 35
A.6.2 Measurement in system commissioning 36
Annex B (informative) Commissioning experiences in Japan 39
B.1 Overview 39
B.2 Regulations 39
B.3 Pre-commissioning in Japan 39
B.3.1 General 39
B.3.2 Combined test 40
B.3.3 Communication system test 41
B.4 System commissioning in Japan 42
B.4.1 General 42
B.4.2 Energizing test 42
B.5 Measurement in system commissioning in Japan 43
B.5.1 General 43
B.5.2 Measurement in system commissioning 44
Annex C (informative) Commissioning experiences in India 51
C.1 Overview 51
C.2 Design, testing, installation, transportation and construction 52
C.3 On-site acceptance tests 53
C.3.1 General 53
C.3.2 1 200/400 kV, 333 MVA single phase transformers 53
C.3.3 1 200 kV dead tank spring-spring type SF_6 circuit-breakers 53
C.3.4 1 200 kV double break centre rotating and knee type disconnector 54
C.3.5 1 200 kV capacitive voltage transformers 54
C.3.6 850 kV surge arrestors 54
C.4 Commissioning 54
Bibliography 56

Figure 1 – General structure of on-site acceptance tests and commissioning 10
Figure A.1 – Circuit for test of UHV transformer with current increasing from zero 31
Figure A.2 – Circuit for test of UHV transformer with voltage increasing from zero 32
Figure A.3 – Circuit for loop closing (interconnecting)/opening (splitting) test operated by UHV transmission line circuit breakers 34
Figure B.1 – Circuit for transient voltage and current measurement 44

Figure B.2 – Analysis results of electrostatic induced field in the vicinity of bushing above the ground 47
Figure B.3 – Electrostatic induction field intensity distribution 47
Figure C.1 – Basic set-up at Bina 1 200 kV National Test Station 52
Figure C.2 – Typical variation in voltage over the period of 4 days at Bina 1 200 kV National Test Station 55

Table 1 – Scope of application 10
Table 2 – Recommended test items of pre-commissioning 11
Table 3 – Recommended test items of system commissioning 13
Table 4 – Recommended measurement items of system commissioning 19
Table 5 – DGA of UHV transformer, UHV reactor and neutral point reactor 21
Table A.1 – Test items for pre-commissioning of UHV AC transmission projects 24
Table A.2 – System commissioning tests for UHV AC transmission projects 28
Table A.3 – Measurement items in system commissioning for UHV AC transmission projects 35
Table B.1 – Pre-commissioning items 39
Table B.2 – System commissioning items 42
Table B.3 – Measurement items in system commissioning 44

UHV AC TRANSMISSION SYSTEMS –

Part 302: Commissioning

FOREWORD

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The text of this Technical Specification is based on the following documents:

DTS	Report on voting
122/115/DTS	122/117/RVDTS

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

A list of all parts in the IEC 63042 series, published under the general title *UHV AC transmission systems*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

Due to the increase in voltage level and transmission capacity, the reliability and security of high voltage electric equipment and power system are facing new challenges. There is a need to have consensus on a series of technical criteria and requirements for commissioning tests for ultra-high voltage (UHV) AC transmission systems to check the proper and expected performance of substation equipment and transmission lines, to verify the function of the transmission system, to obtain the electromagnetic data and confirm the environmental impacts complying with relevant local regulations. By commissioning, the integrated performance and construction quality of the project before its commercial operation could be confirmed.

This document proposes relevant test items, test preconditions, test methods, and test acceptance criteria for pre-commissioning, system commissioning, and measurement during system commissioning.

UHV AC TRANSMISSION SYSTEMS –

Part 302: Commissioning

1 Scope

This part of IEC 63042 applies to the commissioning of UHV AC transmission systems.

It mainly specifies the test purposes, test items, test preconditions, test methods and test acceptance criteria during pre-commissioning and system commissioning. Also, the measurement requirements for system commissioning are specified.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60076-6:2007, *Power transformers – Part 6: Reactors*

IEC 60076-10:2016, *Power transformers – Part 10: Determination of sound levels*
IEC 60076-10:2016/AMD1:2020

IEC 61000-4-13:2002, *Electromagnetic compatibility (EMC) – Part 4-13: Testing and measurement techniques – Harmonics and interharmonics including mains signalling at a.c. power port, low frequency immunity tests*
IEC 61000-4-13:2002/AMD1:2009
IEC 61000-4-13:2002/AMD2:2015

IEC 61786-2:2014, *Measurement of DC magnetic, AC magnetic and AC electric fields from 1 Hz to 100 kHz with regard to exposure of human beings – Part 2: Basic standards for measurements*

IEC TS 63042-301:2018, *UHV AC transmission systems – Part 301: On-site acceptance tests*

CISPR TR 18-2:2017, *Radio interference characteristics of overhead power lines and high-voltage equipment – Part 2: Methods of measurement and procedure for determining limits*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
commissioning
tests and measurements performed to verify the quality of equipment installation and verify the system in an appropriate state before a transmission project being put into commercial operation, consisting of two parts of pre-commissioning and system commissioning

3.2
pre-commissioning
series of tests and measurements performed in a substation before system commissioning of a transmission project

Note 1 to entry: The tests include combined tests and communication tests to further assess the condition of equipment after installation and on-site acceptance test for a transmission project.

3.3
system commissioning
series of tests and measurements performed (or checked) for the equipment and the power system in the operating power grid after pre-commissioning

Note 1 to entry: The tests and measurements are implemented after completing on-site acceptance test and pre-commissioning test, in order to ensure the project fulfils the requirements of commercial operation.

3.4
loop closing
loop interconnecting
operation performed by closing circuit-breaker of transmission line or transformer to make the power grid of same or different voltage levels run in loop (synchronous interconnection) network

Note 1 to entry: The purpose of the test is to verify the correctness of the synchronous strategy set for the tested circuit-breakers, and to ensure security when the power grid is loop closed (interconnected).

3.5
loop opening
loop splitting
operation performed by opening circuit-breaker of transmission line or transformer to make the power grid of same or different voltage levels run out of loop (synchronous interconnection) network

Note 1 to entry: The purpose of the test is to verify the security when the power grid is loop opened (split).

4 General

4.1 Requirements

The overall requirements including main purpose, general method, scope of application, and technical preparation for UHV AC system commissioning are as follows in 4.2 to 4.5 to secure objectivity and transparency for evaluation and judgment of commissioning and to follow the regulation of each country for safety and environmental security.

4.2 Main purpose

Commissioning is performed to confirm the integrated performance capability and construction quality of the project before its commercial operation. The utilities should carry out commissioning tests for UHV equipment and system-oriented aspects before the operation. The purposes are as follows:

- to confirm the proper and expected performance of substation equipment and transmission lines;
- to verify the function of the transmission system;

- to obtain the data such as electromagnetic field, sound level, etc., and to confirm the environmental impacts complying with relevant local regulations.

4.3 General structure of commissioning

The general structure of on-site acceptance tests and commissioning is shown in Figure 1, to confirm the soundness of every equipment and transmission line, the communication test between protection, control, information equipment and control centre, and also the function of the power grid. The commissioning consists of pre-commissioning and system commissioning. Details of pre-commissioning and system commissioning are shown in Clause 5 and Clause 6 respectively.

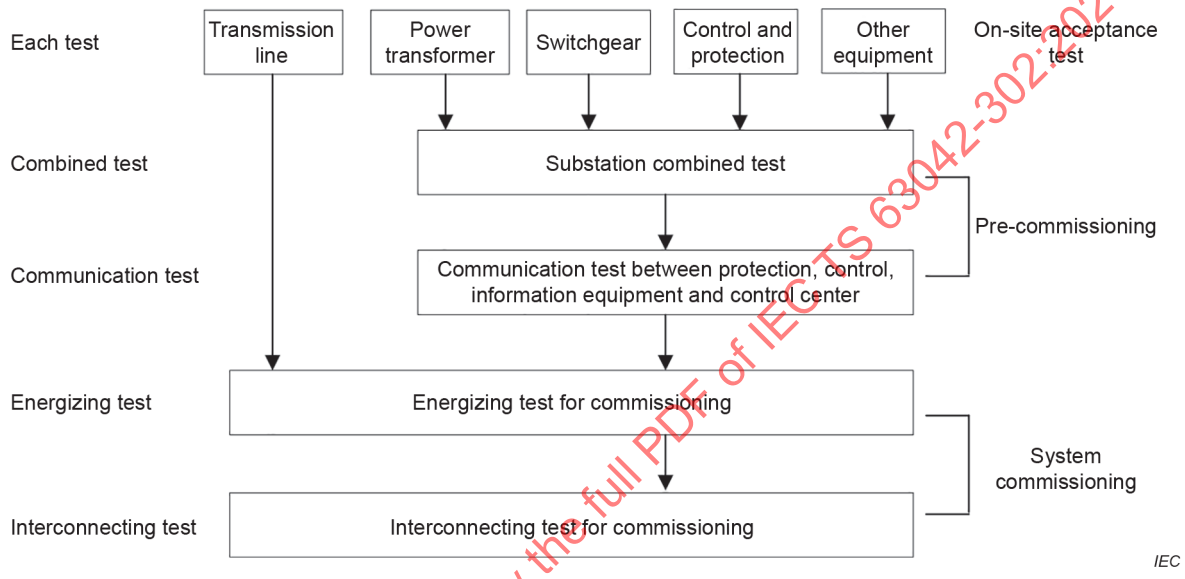


Figure 1 – General structure of on-site acceptance tests and commissioning

4.4 Scope of application

The scope of the application is shown in Table 1.

Table 1 – Scope of application

IEC documents	Each test	Combined test	Communication test	Energizing test	Interconnecting test
IEC TS 63042-301 UHV AC transmission systems – Part 301: On-site acceptance tests	Applied	-	-	-	-
IEC TS 63042-302 UHV AC transmission systems – Part 302: Commissioning	-	Applied	Applied	Applied	Applied

4.5 Technical preparation of system commissioning

With regard to the newly constructed UHV AC substations and transmission lines, simulation analysis should be carried out, as the necessary technical basis for evaluating the risks and ensuring the security and availability of system commissioning tests based on the practical conditions of equipment and nearby power grid including transmission lines.

The simulation analysis consists of two parts, power flow and stability analysis, and electromagnetic transient analysis. The power flow and stability simulation analysis focuses on power grid operation mode, power flow arrangement, fault current, voltage fluctuation, system stability performance during a disturbance, and security control measures. The electromagnetic transient analysis focuses on overvoltage and overcurrent for each commissioning test, and technical measures to ensure the security of equipment and system.

Commissioning program should be prepared prior to on-site implementation, which should specify the test purposes, test contents, test and measurement procedures, and on-site security measures, etc. The commissioning program should be compiled based on the simulation results, the practical connection wirings of the commissioned substations, and the characteristics of commissioned equipment and transmission lines.

5 Pre-commissioning

5.1 General

The conditions of pre-commissioning for UHV AC projects are as follows:

- the installation of equipment has been completed, and on-site acceptance tests are completed;
- the network connection of the protection and control system and the communication system in the station has been completed;
- the AC and DC power supply in the station has been installed and tested.

The test items and requirements of pre-commissioning for UHV AC projects should be specified and selected by utilities based on their regulations and design.

The recommended test items of pre-commissioning are listed in Table 2.

Table 2 – Recommended test items of pre-commissioning

Test items	
Combined test	Protection and control system test
	Instrument transformer test
	Switchgear and transformer test
	AC and DC power supply system test
Communication system test	Monitoring and control system test
	Protection and fault information system test

5.2 Combined test

5.2.1 General

The requirements for each combined test item should be specified.

5.2.2 Protection and control system test

The test contents and method of the protection and control system test are as follows:

- check the insulation of the secondary circuit and panel with a megohmmeter;
- check the signal of the protection and control system. The input/output binary signal is simulated one by one in each protection and control device and then checked at the receiving end (measuring and controlling device, control and monitoring system, or related equipment);

- check the protection and tripping function. The tripping logic of each protection device is tested one by one. Simulate all kinds of faults in each protection to make it trip, check and confirm the correctness of the tripping function between protection and circuit-breaker, the linkage logic between protections such as line protection and circuit-breaker failure protection, busbar protection and circuit-breaker failure protection;
- carry out an end-to-end test. For pilot protection or differential protection, check the sampling value, differential current, input and output contacts, remote signal, and telemetry of the protection devices on both sides, and simulate various faults to verify the logic of pilot or differential protection. Check whether the optical power, bit error rate, attenuation, and channel coding of the channel meet the requirements.

5.2.3 Instrument transformer test

Instrument transformers include current transformer (CT) and voltage transformer (VT). The test contents and method of instrument transformer test are as follows:

- check the insulation of CT and VT secondary circuit insulation with a megohmmeter;
- check the DC resistance of the CT secondary circuit. The balance bridge method or secondary injection method can be applied;
- check and confirm that the polarity of the instrument transformer is in accordance with the design drawings. It could be conducted in the CT primary injection test and VT energizing test;
- check the AC load resistance of the secondary circuit of the instrument transformer. Secondary current and voltage injection method could be applied;
- inject current into the primary system of the CT and check the phase sequence, polarity, and ratio of the current transformer, and the correctness of the display values of protection, measurement, metering, and other related equipment;
- energize the voltage transformer from primary or secondary, check the ratio of voltage transformer, and the correctness of the voltage display value of protection, measurement, metering, and other related equipment.

5.2.4 Switchgear and transformer test

Switchgear includes circuit-breaker, disconnector, and earthing switch. The test contents and method of switchgear and transformer test are as follows:

- under each redundant operating power supply, verify the correctness of local/remote tripping and closing operation of the circuit-breaker, and on-load tap changer (OLTC) remote operation of the transformer;
- simulate simultaneous opening and closing operations to verify the anti-pumping function of the circuit-breaker;
- check and confirm that the current of the opening and closing circuit of the circuit-breaker meets the requirements;
- check and confirm that the low SF_6 gas pressure locking functions of the circuit-breaker work correctly;
- for synchronous closing of the circuit-breaker, when the synchronous conditions are satisfied or not, the closing operation is carried out separately to verify the correctness of the synchronous function;
- for each circuit-breaker, related disconnectors, and related earthing switches, and for circuit-breaker and high-speed earthing switch (HSES) for secondary arc extinction, when the interlocking condition is satisfied or not, the interlocking operation is carried out separately to verify whether the interlocking function is correct. For the details of the interlock between circuit-breaker and high-speed earthing switch see Annex B.

5.2.5 AC and DC power supply system test

AC and DC power supply system refers to the auxiliary power supply of substations. The test contents and method of the AC and DC power supply system test are as follows:

- check insulation resistance of power source busbar and cable to ground;
- the functions of DC system switching, DC insulation monitoring, DC feeder power off, standby self-switching, accident lighting, UPS, control and protection interface should be tested and verified.

5.3 Communication system test

In the communication system test, the communication of all automation and protection systems should be tested. The test contents and method of the communication test are as follows:

- check the binary and analogue signals of each substation equipment, protection and control system, circuit-breaker, disconnector, and earthing switch, and verify the remote control operation;
- collect and record fault waveform, protection actions, and signals for protection and fault information system, which is connected with digital fault recorders and protection devices. Check the signals. Test the communication with the substation and the master station of the protection and fault information system;
- check the insulation of secondary circuit for other monitoring and/or control systems, such as digital fault recorder, fault location system, stability control system, synchronous phasor measurement system, time synchronization system, metering system, on-line condition monitoring system. Check the binary and analogue signals, verify the functions of each system, and test the communication with the master station and/or substation.

NOTE Some of the monitoring and/or control system tests mentioned above are described in Clause A.4.

6 System commissioning

6.1 General

The recommended test items of system commissioning are listed in Table 3, but no sequence is defined.

Table 3 – Recommended test items of system commissioning

Test items	
Energizing test	Energizing test of no-load UHV power transformer
	Energizing test of tertiary connected reactor
	Energizing test of tertiary connected capacitor
	Energizing test of UHV busbar shunt reactor
	Energizing test of UHV busbar
	Energizing test of no-load UHV transmission line
Interconnecting test	Loop closing (interconnecting)/opening (splitting) test

The test items and requirements of system commissioning for UHV AC projects should be specified and selected by utilities based on their own regulations and design.

For newly designed and constructed transmission lines, more information for system commissioning test is given in Annex A to Annex C.

6.2 Test requirements

6.2.1 General

The requirements on preconditions, methods and acceptance criteria for each test item of system commissioning should be specified as described in the following subclauses.

6.2.2 Energizing test of no-load UHV power transformer

6.2.2.1 Test preconditions

The test preconditions for energizing test of no-load UHV power transformers are as follows:

- the tap changer of UHV power transformer should be adjusted according to the requirements of commissioning program;
- substation voltage should be controlled according to the requirements of power grid operation of utilities based on simulation analysis;
- relay protection should be in function, and the value should be set according to the requirements of utilities. It should be avoided to operate the equipment without main protection during the test;
- before the first switching of UHV power transformer or after measuring the winding DC resistor, the demagnetization should be completed before energizing the power transformer.

6.2.2.2 Test methods

The test methods for energizing test of no-load UHV power transformers are as follows:

- the energizing test of no-load UHV power transformer should be carried out with circuit-breaker on the primary side or secondary side of the transformer;
- the continuous running time after the first charging, the running time for each energizing and the interval time for each switching should meet the requirements of utilities.

6.2.2.3 Test acceptance criteria

The test acceptance criteria for energizing test of no-load UHV power transformers are as follows:

- the performance of UHV power transformers should be consistent with their available factory and on-site acceptance tests, for details see IEC TS 63042-301;
- overvoltage and inrush current during switching UHV power transformers should meet design requirements;
- relay protection behavior and signals should be correct for UHV power transformers and circuit-breakers;
- phase signals of secondary voltage should be correct for VT on primary and secondary side of UHV power transformers.

6.2.3 Energizing test of tertiary connected reactor

6.2.3.1 Test preconditions

The test preconditions for energizing test of tertiary connected reactors are as follows:

- substation voltage should be controlled according to the requirements of power grid operation of utilities based on simulation analysis;
- relay protection should be in function, and the value should be set according to the requirements of utilities. It should be avoided to operate the equipment without main protection during the test.

6.2.3.2 Test methods

The test methods for energizing test of tertiary connected reactors are as follows:

- the switching times for each group of tertiary connected reactor during the whole commissioning period should meet the requirements of utilities;
- the running time after the first energizing should meet the requirements of utilities;
- the running time after each energizing and the interval time for each switching should meet the requirements of utilities.

6.2.3.3 Test acceptance criteria

The test acceptance criteria for energizing test of tertiary connected reactors are as follows:

- the performance should be compared to the available factory and on-site acceptance tests results of tertiary connected reactors;
- overvoltage during switching tertiary connected reactors should meet design requirements;
- voltage fluctuation should be consistent with simulation analysis;
- relay protection behavior and signals should be correct for tertiary connected reactors, circuit-breakers and busbars;
- phase signals should be correct for tertiary connected reactors VT secondary voltage;
- temperature of the equipment should be at normal level.

6.2.4 Energizing test of tertiary connected capacitor

6.2.4.1 Test preconditions

The test preconditions for energizing test of tertiary connected capacitors are as follows:

- substation voltage should be controlled according to the requirements of power grid operation of utilities based on simulation analysis;
- relay protection should be in function, and the setting value should be set according to the requirements of utilities. It should be avoided to operate the equipment without main protection during the test.

6.2.4.2 Test methods

The test methods for energizing test of tertiary connected capacitors are as follows:

- the switching times for each group of tertiary connected capacitor during the whole commissioning period should meet the requirements of utilities;
- the running time after the first energizing should meet the requirements of utilities;
- the running time after each energizing and the interval time for each switching should meet the requirements of utilities.

6.2.4.3 Test acceptance criteria

The test acceptance criteria for energizing test of tertiary connected capacitors are as follows:

- the performance should be compared to the available factory and on-site acceptance tests results of tertiary connected capacitors;
- overvoltage during switching tertiary connected capacitors should meet design requirements;
- voltage fluctuation of tertiary side busbar should be consistent with simulation analysis;
- current and unbalanced current of tertiary connected capacitors should be consistent with design requirement;

- relay protection behavior and signals should be correct for tertiary connected capacitors, circuit-breakers and busbars.

6.2.5 Energizing test of UHV busbar shunt reactor

6.2.5.1 Test preconditions

The test preconditions for energizing test of UHV busbar shunt reactors are as follows:

- substation voltage should be controlled according to the requirements of power grid operation of utilities based on simulation analysis;
- relay protection should be in function, and the setting value should be set according to the requirements of utilities. It should be avoided to operate the equipment without main protection during the test.

6.2.5.2 Test methods

The test methods for energizing test of UHV busbar shunt reactors are as follows:

- high voltage reactor energizing test should be carried out with UHV circuit breaker;
- when UHV shunt reactor is installed on substation busbar, the switching times for reactor during the whole commissioning period should meet the requirements of utilities;
- the continuous running time after the first energizing should meet the requirements of utilities;
- the running time of each energizing and the interval time for each switching should meet the requirements of utilities.

6.2.5.3 Test acceptance criteria

The test acceptance criteria for energizing test of UHV busbar shunt reactors are as follows:

- the performance should be consistent with available factory and on-site acceptance tests results of UHV shunt reactors, for details see IEC TS 63042-301;
- overvoltage during switching UHV busbar shunt reactors should meet design requirements;
- relay protection behavior and signals should be correct for UHV busbar shunt reactors, circuit-breakers and busbars;
- phase signals should be correct for UHV busbar shunt reactors VT secondary voltage.

6.2.6 Energizing test of UHV busbar

6.2.6.1 Test preconditions

The test preconditions for energizing test UHV busbar are as follows:

- the tap changer and system voltage of UHV power transformer if involved in commissioned substation should be adjusted according to the requirements of commissioning program;
- substation voltage should be controlled according to the requirements of power grid operation of utilities based on simulation analysis;
- if an open-phase tripping or closing occurs at any UHV circuit-breaker that involved, the three-phase of the circuit-breaker should be tripped immediately;
- the reclosing function of UHV test line if involved should be withdrawn before energizing the line. If fault occurs in the UHV line, the line should be switched off immediately;
- relay protection should be in function during the test, and the setting value should be set according to the requirements of utilities. It should be avoided to operate the equipment without main protection during the test.

6.2.6.2 Test methods

The test methods for energizing test of UHV busbar are as follows:

- each group of UHV circuit-breakers should be operated with three-phase closing and opening method;
- the interval time for each switching should meet the requirements of utilities.

6.2.6.3 Test acceptance criteria

The test acceptance criteria for energizing test of UHV busbar are as follows:

- the performance of busbar and other equipment connected to the UHV busbar should be compared to available factory and on-site acceptance tests results, for details see IEC TS 63042-301;
- the overvoltage during switching UHV busbar should meet design requirements;
- relay protection behaviors and signals should be correct for UHV busbars, circuit-breakers and lines if involved;
- phase signals should be correct for UHV busbar and its VT secondary voltage;
- working conditions of UHV busbars and both line terminal arresters if involved should be normal.

6.2.7 Energizing test of no-load UHV transmission line

6.2.7.1 Test preconditions

The test preconditions for energizing test of no-load UHV transmission lines are as follows:

- the tap changer and system voltage of UHV power transformer in commissioned substation should be adjusted according to the requirements of commissioning program;
- substation voltage should be controlled according to the requirements of power grid operation of utilities based on simulation analysis;
- the reclosing function of UHV test line should be withdrawn before energizing the line. If fault occurs in the UHV test line, the line should be switched off immediately;
- if an open-phase tripping or closing occurs at any end of a UHV test line circuit-breaker, the three-phase of the circuit-breaker should be tripped immediately;
- relay protection should be in function during the test, and the setting value should be set according to the requirements of utilities. It should be avoided to operate the equipment without main protection during the test.

6.2.7.2 Test methods

The test methods for energizing test of no-load UHV transmission lines are as follows:

- each group of UHV circuit-breakers should be operated with three-phase closing and opening method;
- when UHV lines are installed or not installed with shunt reactors, the running time after the first energizing should meet the requirements of utilities;
- the interval time for each switching should meet the requirements of utilities.

6.2.7.3 Test acceptance criteria

The test acceptance criteria for energizing test of no-load UHV transmission lines are as follows:

- the performance of insulators and other equipment connected to the UHV transmission line should be compared to available factory and on-site acceptance tests results, for details see IEC TS 63042-301;

- the overvoltage during switching UHV no-load lines should meet design requirements;
- relay protection behavior and signals should be correct for UHV busbars, circuit-breakers and lines;
- phase signals should be correct for UHV busbars and lines VT secondary voltage;
- working conditions of UHV busbars and both line terminal arresters should be normal.

6.2.8 Loop closing (interconnecting)/opening (splitting) test

6.2.8.1 Test preconditions

The test preconditions for loop closing (interconnecting)/opening (splitting) test are as follows:

- the tap changer of UHV power transformer in commissioned substation should be adjusted according to the requirements of commissioning program;
- substation voltage should be controlled according to the requirements of power grid operation of utilities based on simulation analysis;
- the two sides of the loop closing (interconnecting) point are correctly checked with the same power supply;
- relay protection and security control devices should be in function, and the setting value should be set according to the requirements of utilities. It should be avoided to operate the equipment without main protection during the test;
- the looping-in strategy (including angle difference and voltage difference) of the synchronizing devices of UHV line circuit-breakers of should be set based on simulation analysis;
- the reclosing function of UHV test line circuit-breakers should be put into operation, and the single-phase reclosing time of UHV line circuit-breakers should be set based on simulation analysis.

6.2.8.2 Test methods

The test methods for loop closing (interconnecting)/opening (splitting) test are as follows:

- loop closing (simulated-synchronization interconnecting)/opening (splitting) tests are carried out with both side circuit-breakers of UHV line and secondary side circuit-breakers of UHV power transformer;
- for those cases being not able to apply the secondary winding side circuit-breakers of UHV power transformer, the UHV line circuit-breakers should be applied for test;
- for the case that the short circuit capacity of the commissioning system is small or there is no no-load UHV power transformer fed by secondary side power grid due to other reasons, the circuit-breakers on secondary winding side of UHV power transformer should be applied for test.

6.2.8.3 Test acceptance criteria

The test acceptance criteria for loop closing (interconnecting)/opening (splitting) test are as follows:

- function of synchronization looping-in should be normal;
- voltage and phase angle difference across circuit-breakers for loop closing/opening of UHV lines or UHV power transformers should be below pre-setting value;
- phase signals should be correct for VT of UHV lines or UHV power transformers;
- relay protection behavior and signals should be correct for UHV lines, power transformer, circuit-breakers and busbars;
- behavior of security control devices should be correct.

7 Measurement in system commissioning

7.1 General

Results of measurement in system commissioning should be reference value for the following commissioning tests and initial value for maintenance.

The recommended measurement items in system commissioning are listed in Table 4.

Table 4 – Recommended measurement items of system commissioning

Measurement items	Subclause
Transient voltage and current measurement	7.2.1
Electric quantity measurement	7.2.2
Relay protection measurement	7.2.3
Harmonic measurement	7.2.4
Sound level measurement of power transformer/shunt reactor	7.2.5
Vibration measurement of power transformer/shunt reactor	7.2.6
Dissolved gas analysis (DGA) of power transformer/shunt reactor	7.2.7
Temperature measurement	7.2.8
Power frequency electric and magnetic field measurement of substation/transmission line	7.2.9
Audible noise measurement of substation/transmission line	7.2.10
Radio interference measurement of transmission line	7.2.11
Partial discharge monitoring in gas insulated switchgear (GIS)/power transformer	7.2.12

NOTE Other measurement items are detailed in Clause A.6.

7.2 Measurement requirements

7.2.1 General

The requirement for general conditions and items of measurement during system commissioning for UHV AC projects should be specified and selected by utilities based on their own regulations.

The requirements for methods and contents of each measurement item are specified.

7.2.2 Transient voltage and current measurement

The measurement requirements and conditions are as follows:

- the sampling rate of the measuring equipment should meet the requirements of utilities;
- the recording time should meet the requirements of utilities.

The measurement contents are as follows:

- measure the transient voltage of UHV power transformer on the primary side, shunt reactor, neutral point reactor, busbar at the beginning and end terminal of transmission line. Measure the transient current of circuit-breaker and neutral point reactor, and record arrester action times;
- measure the transient voltage of UHV power transformer on the secondary side and record arrester action times;
- measure the transient voltage of UHV power transformer on the tertiary side, compensation capacitor and its neutral point, compensation reactor and its neutral point.

Measure transient current of compensation capacitor and reactor, and record arrester action times.

7.2.3 Electric quantity measurement

The measurement requirements and conditions are as follows:

- the electric quantity should be measured for all system commissioning items or meet the requirements of utilities;
- the measuring instrument is connected to the secondary side of VT and CT of the relevant equipment;
- the sampling rate of the measuring instrument and the recording time should meet the requirements of utilities.

The measurement contents are as follows:

- the voltage and current signals of the related lines or equipment should be sampled and recorded;
- the parameters such as frequency, active power and reactive power are measured and calculated.

7.2.4 Relay protection measurement

The measurement requirements and conditions are as follows:

- the relay protection measurement should be carried out during system commissioning and after the system is in stable status;
- the secondary current for checking phase should meet the requirements of utilities.

The measurement contents are as follows:

- check the phase and amplitude of the secondary voltage circuit;
- check the phase and amplitude of the secondary current circuit.

7.2.5 Harmonic measurement

The measurement requirements and conditions are as follows:

- measure the background harmonic of the current system under the condition that UHV system is not in operation;
- measure the harmonic of each side of UHV transformer without load at the primary side of the transformer;
- measure the harmonic of each side of UHV transformer with no-load line at the primary side of the transformer;
- measure the harmonic of each side of UHV transformer with load in the UHV system.

For details see IEC 61000-4-13.

7.2.6 Sound level measurement of power transformer/shunt reactor

The measurement should be carried out during system commissioning, and should meet the requirements in 11.2 of IEC 60076-10: 2016.

The measurement contents are as follows:

- measure the background noise level before the power transformer and shunt reactor are energized;
- measure the sound level when the power transformer and shunt reactor are energized.

7.2.7 Vibration measurement

The measurement should be carried out during system commissioning, and should meet the requirements in 7.8.13 of IEC 60076-6:2007.

The measurement contents are as follows:

- measure the vibration displacements of the oil tank walls, the maximum peak-to-peak amplitude of the displacement and analyse the vibration and local vibration problems if exist, under no-load and load conditions for UHV power transformer;
- measure the vibration displacements of the oil tank walls, the maximum peak-to-peak vibration displacement, and analyse the vibration and local vibration problems if exist, under the live condition for UHV shunt reactor.

7.2.8 DGA of power transformer/shunt reactor

During system commissioning, before energizing and after operating for a certain time at rated voltage, DGA of power transformer, shunt reactor and neutral point reactor should be respectively carried out once.

Besides, the DGA should also be carried out after the following test items, as shown in Table 5.

Table 5 – DGA of UHV transformer, UHV reactor and neutral point reactor

System commissioning items	Power transformer	Shunt reactor	Neutral point reactor
Energizing test of no-load UHV power transformer	Measure	—	—
Energizing test of UHV busbar shunt reactor	—	Measure	—
Energizing test of no-load UHV transmission line	—	Measure (when shunt reactor installed on the line)	Measure (when shunt reactor installed on the line)
Loop closing (interconnecting)/opening (splitting) test	Measure	Measure	—

7.2.9 Temperature measurement

The measurement requirements and conditions are as follows:

- temperature measurement should be carried out for UHV line or equipment under rated voltage and load operation conditions;
- during temperature measurement, the load current of each equipment should be recorded;

The measurement contents are as follows:

- temperature measurement should be carried out at the bushing and the connector, the surface of the tank, the inlet and outlet of the cooler of UHV power transformer, UHV shunt reactor and its neutral point reactor;
- temperature measurement should be carried out at the connector of the bushing of UHV GIS;
- temperature measurement should be carried out at the body and the connector of tertiary reactor and tertiary capacitor;
- temperature measurement should also be carried out at the connector of other equipment according to the requirements of utilities.

7.2.10 Power frequency electric and magnetic field measurement of substation and transmission line

The measurement requirements and conditions are as follows:

- the power frequency electric field is measured under rated voltage for UHV line or equipment;
- the power frequency magnetic field is measured for UHV line or equipment under the load condition.

The measurement contents refer to 5.1 and 5.3 of IEC 61786-2:2014, and the measuring points are selected at the following locations:

- power frequency electric and magnetic field measurement inside the substation;
- power frequency electric and magnetic field measurement outside the substation;
- power frequency electric and magnetic field measurement for transverse distribution outside the substation;
- power frequency electric and magnetic field measurement for transverse distribution of transmission line;
- power frequency electric and magnetic field measurement at sensitive points of transmission line.

7.2.11 Audible noise measurement of substation and transmission line

The measurement requirements and conditions are as follows:

- the measurement should be carried out under rain-free and snow-free weather conditions. Considering the influence of weather, correction according to ambient noise should be carried out if necessary;
- the measurement of audible noise inside and outside the substation should be carried out under the load condition for UHV line or equipment;
- the measurement of audible noise on the line should be carried out for UHV line under rated voltage.

The measurement should be carried out at the following locations:

- audible noise measurement inside the substation;
- audible noise measurement outside the substation;
- audible noise measurement at sensitive point outside the substation;
- audible noise measurement for transverse distribution of transmission line;
- audible noise measurement at sensitive points of transmission lines.

7.2.12 Radio interference measurement of transmission line

The measurement requirements and conditions are as follows:

- the measurement should be carried out under the rated voltage for UHV line or equipment;
- the measurement should be carried out under sunny and dry conditions.

The measurement should be carried out outside the substation and under the transmission line. For details see 4.2 of CISPR TR 18-2:2017.

7.2.13 Partial discharge monitoring in GIS/power transformer

See 5.15 and 7.2 of IEC TS 63042-301:2018 for partial discharge monitoring in GIS/power transformers.

Annex A
(informative)

Commissioning experiences in China

A.1 General

This annex describes the commissioning experiences in China for UHV AC transmission systems.

A.2 Overview

In 2009, China constructed and put into commercial operation the first UHV AC pilot demonstration project (Jindongnan-Nanyang-Jingmen Project). The UHV AC transmission line is 640 km long and applies the single erection mode. The project consists of 2 UHV AC substations and one UHV AC switching station and includes 2 groups of 3 000 MVA UHV transformers. The UHV switchgear applies GIS and Mixed Technology Switchgear (MTS) types. The project was the world's only commercial UHV AC transmission project at that time.

In 2013, China built the first UHV AC double-circuit transmission demonstration project (Huainan-Hainan-Shanghai project), which is the second UHV AC project in China. The total length of the UHV AC transmission line is 650 km, and it takes the double-circuit in the same tower erection mode for the first time. The project consists of 4 UHV AC substations, also includes 7 groups of 3 000 MVA UHV transformers, and the UHV switchgear applies GIS and MTS types.

Till the end of 2020, 14 UHV AC transmission projects have been built and put into commercial operation in China. Besides, more than 10 extension projects implemented within single substation are constructed. All the above projects are in stable operation, which has significantly enhanced the structural strength of China's large power grid, improved the security and reliability of the power grid, and fully exerted the advantages of resource sharing and accident support in the large power grid. UHV AC technology and projects have shown good technical, economic, and advanced nature. Based on this, more new and extended projects are continuously under construction in China presently.

A.3 Regulations

Before the commercial operation of all UHV AC transmission projects, comprehensive and rigorous commissioning tests have been conducted in China. According to the implementation sequence, China's power transmission project commissioning work is divided into three parts: On-site acceptance tests, sub-system commissioning (similar to pre-commissioning), and system commissioning. These tests provide a reliable guarantee for the project to be smoothly put into commercial operation and in long-term stable operation. China also established a standardized process for commissioning, and many Chinese national power industry and enterprise technical standards on commissioning have been formulated, in which numerous successful commissioning experiences were integrated.

A.4 Pre-commissioning

Sub-system commissioning (pre-commissioning) test for a UHV AC transmission project is carried out in China after on-site acceptance tests. It is tested for station secondary equipment applied for functions such as relay protection, control, measurement, metering, fault recording, monitoring, communication, automation, sequence control system, as well as auxiliary power systems including station power supply and firefighting facilities. Through these tests, the coordination action correctness among individual equipment and also the correctness of various control commands and information transmission are verified.

Before the on-site implementation of the pre-commissioning, the commissioning program is prepared, which specifies the test purposes, test contents, test and measurement procedures, on-site security measures, and so on. Typical pre-commissioning tests for UHV AC transmission projects in China are listed in Table A.1.

Table A.1 – Test items for pre-commissioning of UHV AC transmission projects

No.	Test classification	Test items	Description	Remarks
1	Relay protection and control system test	Secondary circuit check	Check the correctness of the secondary circuit wiring. Check the insulation of the secondary circuit and panel with a megohmmeter.	Mandatory
2		Signal check of protection and control	The input/output binary signal is simulated one by one in each protection and control device and then checked at the receiving end (measuring and controlling device, control and monitoring system, or related equipment).	Mandatory
3		Protection system test	The tripping logic of each protection device is checked one by one. Simulate all kinds of faults in each protection to make it tripping, check and confirm the correctness of the tripping function between protection and circuit-breaker, the linkage logic between protections such as line protection and circuit-breaker failure protection, busbar protection and circuit-breaker failure protection.	Mandatory
4		End-to-end test	For pilot protection or differential protection, check the sampling value, differential current, input and output contacts, remote signal and telemetry of the protection devices on both sides, and simulate various faults to verify that the logic of pilot or differential protection works correctly. Check whether the optical power, bit error rate, attenuation, and channel coding of the channel meet the requirements.	Mandatory
5		Stability control system test	The stability control system is composed of several stability control devices, which can realize emergency control functions such as generator tripping, load shedding, and quick power reduction. Check the insulation of the secondary circuit and communication of the stability control system; verify the functions of the stability control system; test the communication and function with the stability control systems of relevant plant and station.	Optional
6	AC current and voltage test	Insulation check of CT and VT secondary circuit	Check the insulation of the secondary circuit of the instrument transformer with a megohmmeter.	Mandatory
7		DC resistance check of CT secondary circuit	Check the DC resistance of the secondary circuit of the instrument transformer. The balance bridge method or secondary injection method can be applied.	Mandatory
8		CT and VT secondary ac load test	Check the AC load resistance of the secondary circuit of the instrument transformer. Secondary current and voltage injection method can be applied.	Mandatory
9		Polarity test	Check and confirm that the polarity of the instrument transformer is in accordance with the design drawings. Secondary current and voltage injection method can be applied.	Mandatory
10		CT/VT injection test	Inject current or voltage into the primary or secondary circuit of the instrument transformer, check the ratio and phase sequence, and the correctness of current or voltage display value of protection, measurement, metering, and other related equipment.	Optional

No.	Test classification	Test items	Description	Remarks
11	Switchgears and transformer test	Local/remote operation test (including OLTC remote operation test)	Under each duplicated operating power supply, verify the correctness of local/remote tripping and closing operation of the circuit-breaker, and on-load tap changer (OLTC) remote operation of the transformer.	Mandatory
12		Non-electrical parameter test	Check the secondary circuit of the fan, oil pump, gas, oil temperature, and other non-electrical parameters of transformers and conduct the non-electrical parameter test.	Mandatory
13		Anti-pumping relay test	Simulate simultaneous opening and closing operations to verify the anti-pumping function of the circuit-breaker.	Mandatory
14		Opening and closing circuit current check	Check and confirm that the current of the control circuit for opening and closing circuit-breaker meets the requirements.	Optional
15		Circuit-breaker lock out test	Check the opening and closing functions of the circuit-breaker with low SF_6 gas pressure.	Mandatory
16		Circuit-breaker simultaneous closing circuit Test	For synchronous closing of the circuit-breaker, when the synchronous conditions are satisfied or not, the closing operation is carried out separately to verify the correctness of the synchronous function.	Mandatory
17		Circuit-breaker and disconnector/ (high speed) earthing switch interlock test	For each circuit-breaker and disconnector/(high speed) earthing switch, when the interlocking condition is satisfied or not, the interlocking operation is carried out separately to verify whether the interlocking function is correct.	Mandatory
18	AC and DC power supply system test	Busbar and cable insulation check	Check insulation resistance of power source busbar and cable.	Mandatory
19		Functional test and circuit check	Carry out station AC power supply switching (standby automatic switching) test, DC power gradation difference test, switching test, DC insulation monitoring, DC feeder power off test, accident lighting and UPS test, protection power circuit check.	Mandatory
20	Communication system test	Control and monitoring system test	Check the remote signal and telemetry of protection and control system, AC and DC power supply, circuit-breakers, disconnectors, earthing switches, and other equipment, and verify the remote control operation and synchronization functions. Carry out the sequence control function test of the circuit-breaker to verify the effectiveness of the sequence control circuit.	Mandatory
21		Protection and fault information system test	Protection and fault information system, which connecting with digital fault recorders and protection devices, collects and records fault waveform and protection actions and signals. Check the signals of the protection and control system; verify the function of the protection and fault information system; test the communication with the master station of the protection information system.	Optional
22		Fault recording system test	Fault recording system refers to digital fault recorders. Check the insulation of the secondary circuit and communication of the fault recording system; check the binary and analogue signals, verify the functions of the fault recording system; test the communication with the master station of the fault recording system.	Optional

No.	Test classification	Test items	Description	Remarks
23		Telecontrol system test	Verify the communication of the telecontrol system with the master station, verify that the telecontrol system correctly displays the binary and analogue status of substation equipment, and can correctly operate circuit-breakers, disconnectors, earthing switches, and other equipment.	Optional
24		Time synchronization system test	Timing synchronization system generally uses GPS to provide accurate timing for protection and automation devices. Check the insulation of the secondary circuit and communication of the time synchronization system; verify the function of the timing system to ensure that the secondary system can receive the time synchronization signal and display the time correctly.	Mandatory
25		Fault Location system test	Check the insulation of the secondary circuit and communication of fault location system; test the communication with the other side of the fault location system.	Optional
26		Synchronous phasor measurement system test	Check the insulation of the secondary circuit and communication of the synchronous phasor measurement system; test the communication with the master station of the synchronous phasor measurement system.	Optional
27		Metering system test	Check the insulation of the secondary circuit and communication of the metering system; verify the function of the metering system; test the communication with the master station of the metering system.	Optional
28		On-line condition monitoring system test	Check the secondary circuit insulation and communication of the on-line condition monitoring system; verify the functions of the on-line condition monitoring system of each equipment; test the communication with the master station.	Optional
29		Firefighting system test of transformer and reactor	Check the insulation of the secondary circuit and communication of the firefighting system; verify the function of the firefighting system.	Optional

A.5 System commissioning

A.5.1 General

System commissioning is performed after on-site acceptance tests and pre-commissioning (sub-system commissioning). A series of tests and measurements are carried out for station equipment and transmission lines to ensure the project to be fully qualified for commercial operation.

A.5.2 Technical preparations

Before system commissioning, detailed technical preparations are carried out, including simulation analysis and making system commissioning program, as follows:

- make simulation calculations on the security and stability issues of the power grid under various test operating conditions and fault conditions during the system commissioning. The system operation mode arrangement, reactive voltage control strategy, security and stability control measures and other operation control measures to ensure the security of the power system are proposed during the commissioning;
- make simulation calculations on the transient voltage, transient current, secondary arc current, recovery voltage, induced voltage and current under various test operation

conditions and fault conditions during system commissioning, and propose test conditions and measures to ensure equipment security;

- based on the simulation analysis results of system commissioning, and combined with the power grid and project conditions, the system commissioning program has to be prepared. The main contents include: test items, test purposes, test contents, power grid operation mode, voltage control requirement, operation steps, measurement items and security measure requirements;
- according to the simulation analysis results, system commissioning program and on-site conditions, the system commissioning measurement program has to be prepared. The main contents include measurement purposes, measurement contents and conditions, measurement instruments, measurement methods and wirings, security measure requirements;
- based on the simulation analysis results and system commissioning program, the system commissioning dispatch program will be prepared. The main contents include requirements for power grid and equipment status, the scope of commissioning equipment and isolation measures, operation process, security measures, organizational measures, technical measures, and accident handling principles during commissioning.

A.5.3 Confirmation on preconditions for on-site commissioning

Prior to the on-site implementation of system commissioning, all the related preconditions should be confirmed, in order to make sure the tests could be carried out as expected and with safety for personnel and equipment. The main preconditions include:

- the division responsibilities for participants of the on-site commissioning are defined;
- the system commissioning program and dispatch program is approved;
- all personnel participating in the test have been on duty, own relevant qualifications, and are familiar with the test process;
- all the equipment and transmission lines to be tested are qualified to be energized;
- all the relevant safety measures and emergency facilities are prepared;
- the application for the on-site commissioning is approved by the dispatch and operation department of the involved utilities.

A.5.4 System commissioning tests

A.5.4.1 General

Typical system commissioning tests for UHV AC transmission projects in China are listed in Table A.2.

Table A.2 – System commissioning tests for UHV AC transmission projects

No.	Test items		Remarks
1	Energizing test	Energizing test of no-load UHV power transformer	Mandatory
2		Energizing test of the tertiary connected reactor	Mandatory
3		Energizing test of the tertiary connected capacitor	Mandatory
4		Energizing test of UHV busbar shunt reactor	Mandatory
5		Energizing test of no-load UHV busbar	Optional
6		Energizing test of no-load UHV switchgear	Optional
7		Energizing test of no-load UHV transmission line	Mandatory
8		Test of UHV power transformer with current increasing from zero	Optional
9		Test of UHV AC transmission line with current increasing from zero	Optional
10		Test of UHV power transformer with voltage rising from zero	Optional
11		Test of UHV AC transmission line with voltage rising from zero	Optional
12	Interconnecting test	Loop closing (interconnecting)/opening (splitting) test	Mandatory
13		Artificial single phase to ground fault test	Optional

The purposes and methods for the above typical system commissioning tests are as follows.

A.5.4.2 Energizing test of no-load UHV power transformer

a) Purpose

This test is performed for all UHV AC stations with newly constructed UHV transformers. The main purposes include the following:

- to examine the insulation performance of the transformer;
- to verify the compliance of the transient voltage and inrush current with design requirements;
- to verify the influences of the inrush current on the relay protection devices;
- to carry out the secondary voltage phase-check of VTs for UHV transformer;
- to monitor the status of relevant arresters during the test.

b) Method

Utilize the primary or secondary side circuit-breaker to carry out the switching test of no-load UHV transformer for at least 5 times. The continuous running time should be not less than 30 min after the first charging. The interval time between each switching should be not less than 5 min. Relay protection should be in function previously, so as to guarantee the security for unexpected fault. Before the first switching of UHV transformer or after measuring the winding DC resistance, the demagnetization should be completed before energizing the transformer.

A.5.4.3 Energizing test of tertiary connected reactor

a) Purpose

This test is performed for all UHV AC stations with newly constructed tertiary connected reactors. The main purposes include the following:

- to examine the insulation performance of the tertiary connected reactors;
- to check the phase and amplitude of the secondary current circuit of relevant relay protection devices;
- to monitor the operation of relevant arresters during the test;

- to examine heating of the relevant equipment.

b) Method

Each group of tertiary connected reactor should be tested for not less than 3 times during the whole commissioning, and the running time after the first charging should be not less than 15 min. The interval time between each switching should be not less than 5 min.

A.5.4.4 Energizing test of tertiary connected capacitor

a) Purpose

This test is performed for all UHV AC stations with newly constructed tertiary connected capacitors. The main purposes include the following:

- to examine the insulation performance of the tertiary connected capacitors;
- to verify the compliance of the transient voltage and inrush current with design requirements;
- to check the phase and amplitude of the secondary current circuit of relevant relay protection devices;
- to monitor the operation of relevant arresters during the test;
- to examine heating for the relevant equipment.

b) Method

Each group of tertiary connected capacitor should be tested for not less than 3 times during the whole commissioning, and the running time after the first charging should be not less than 15 min. The interval time should be not less than 15 min for each switching.

A.5.4.5 Energizing test of UHV busbar shunt reactor

a) Purpose

This test is performed for all UHV AC stations with newly constructed UHV busbar shunt reactors. The main purposes include the following:

- to examine the insulation performance of the tertiary connected reactors;
- to check the phase and amplitude of the secondary current circuit of relevant relay protection devices;
- to carry out the secondary voltage phase-check of VTs for UHV busbar shunt reactor;
- to monitor the operation of relevant arresters during the test;
- to examine heating and corona for the relevant equipment.

b) Method

Each group of tertiary connected reactor should be tested for not less than 3 times during the whole commissioning. The continuous running time should be not less than 30 min after the first charging. The running time of each energizing should be not less than 5 min, and the interval time should be not less than 5 min for each switching.

A.5.4.6 Energizing test of UHV busbar

a) Purpose

This test is performed for the UHV AC stations with newly constructed or extended UHV busbar. In most instances, the test is integrated into other tests such as the energizing test of transformers, transmission lines and so on. The main purposes include the following:

- to examine the insulation performance of the UHV busbar;
- to carry out the secondary voltage phase-check of relevant VTs;
- to monitor the operation of relevant relay protection devices and arresters during the test.

b) Method

Each group of UHV circuit-breakers operates by three-phase closing and switching mode, and the number of switching operations should be not less than once. The interval time should be not less than 5 min for each switching.

A.5.4.7 Energizing test of UHV switchgear

a) Purpose

This test is performed for the UHV AC stations with newly constructed or extended UHV switchgears. In most times, the test is integrated into other tests such as the energizing test of transformers, transmission lines, etc. However, when the switchgear is the only equipment qualified to be tested, this test will be implemented individually. The main purposes include the following:

- to examine the insulation performance of the UHV switchgear;
- to check the phase and amplitude of the secondary current circuit of relevant relay protection devices;
- to carry out the secondary voltage phase-check of relevant VTs.

b) Method

Each group of UHV circuit-breakers operates by three-phase closing and opening method, and should be operated not less than once. The interval time should be not less than 5 min for each switching.

A.5.4.8 Energizing test of no-load UHV transmission line

a) Purpose

This test is carried out for all UHV AC stations with newly constructed UHV transmission lines. The main purposes include the following:

- to examine the insulation performance of the transmission lines;
- to verify the compliance of the transient voltage with design requirements;
- to check the phase and amplitude of the secondary current circuit of relevant relay protection devices;
- to carry out the secondary voltage phase-check of relevant VTs;
- to monitor the operation of relevant arresters during the test.

b) Method

Each group of UHV line circuit-breakers operates by three-phase closing and opening method, and the transmission lines should be switched on/off for not less than 3 times during the whole commissioning. When UHV lines are installed with shunt reactors, the running time after the first energizing should be not less than 30 min. The interval time should be not less than 5 min for each switching.

A.5.4.9 Test of UHV power transformer with current increasing from zero

a) Purpose

This test is performed in Jindongnan-Nanyang-Jingmen UHV AC pilot transmission project. The main purposes include the following:

- to verify the current carrying capacity of the equipment;
- to verify the compliance of the short circuit impedance characteristic of UHV transformer with design requirements;
- to check the phase and amplitude of the secondary current circuit of relevant relay protection devices.

b) Method

This test is carried out in an isolated power grid, which includes a power generator, step-up transformer, EHV transmission line and UHV transformer. The test is implemented on the primary side (or secondary side) and tertiary side of the UHV transformer respectively. The temporary earthing device is installed at the current raising side (no-load side) of UHV transformer, and its current carrying capacity is specified according to the previous simulation analysis results with a certain margin.

Figure A.1 shows an example of circuit for test of UHV transformer with current increasing from zero.

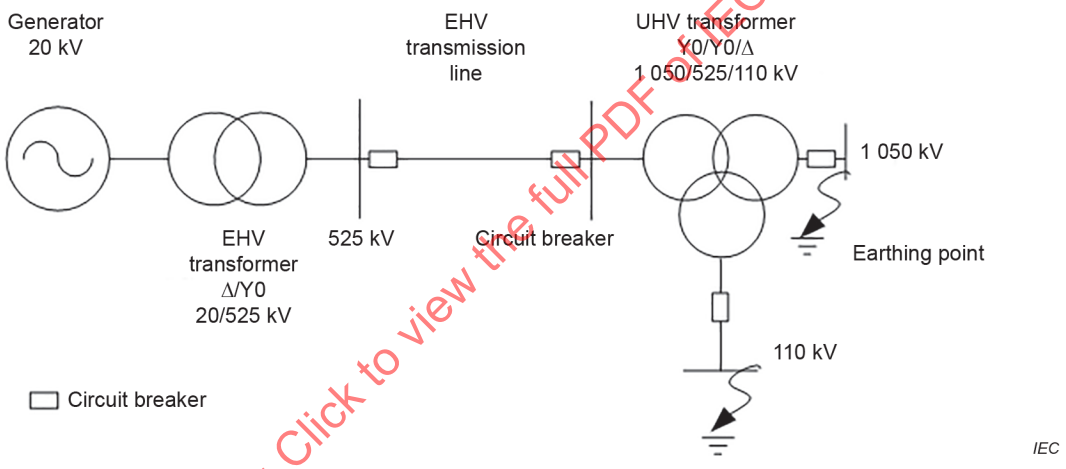


Figure A.1 – Circuit for test of UHV transformer with current increasing from zero

A.5.4.10 Test of UHV AC transmission line with current increasing from zero

a) Purpose

This test is performed in Jindongnan-Nanyang-Jingmen UHV AC pilot transmission project. The main purposes include the following:

- to verify the current carrying capacity of the equipment;
- to check the phase and amplitude of the secondary current circuit of relevant relay protection devices.

b) Method

This test is carried out in an isolated power grid, which includes a power generator, step-up transformer, EHV transmission line, UHV transformer, and UHV transmission line. The test is implemented at the end of the UHV transmission line. The temporary earthing device is installed at the current raising side (non power side) of UHV transmission line, and its current carrying capacity is specified according to the previous simulation analysis results with a certain margin.

A.5.4.11 Test of UHV power transformer with voltage increasing from zero

a) Purpose

This test is performed in Jindongnan-Nanyang-Jingmen UHV AC pilot transmission project. The main purposes include the following:

- to examine the insulation performance of UHV transformer;
- to verify the compliance of the no-load characteristic and no-load loss of the transformer with design requirements;
- to carry out the secondary voltage phase-check of relevant VTs.

b) Method

This test is carried out in an isolated power grid, which includes a power generator, step-up transformer, EHV transmission line and UHV transformer. Prior to the test, the simulation analysis on the self-excitation issue should be done and necessary countermeasures such as putting enough shunt reactors into operation to avoid the self-excitation risk. The voltage of the primary side of the UHV transformer is gradually increased to the maximum voltage.

Figure A.2 shows an example of circuit for test of UHV transformer with voltage increasing from zero.

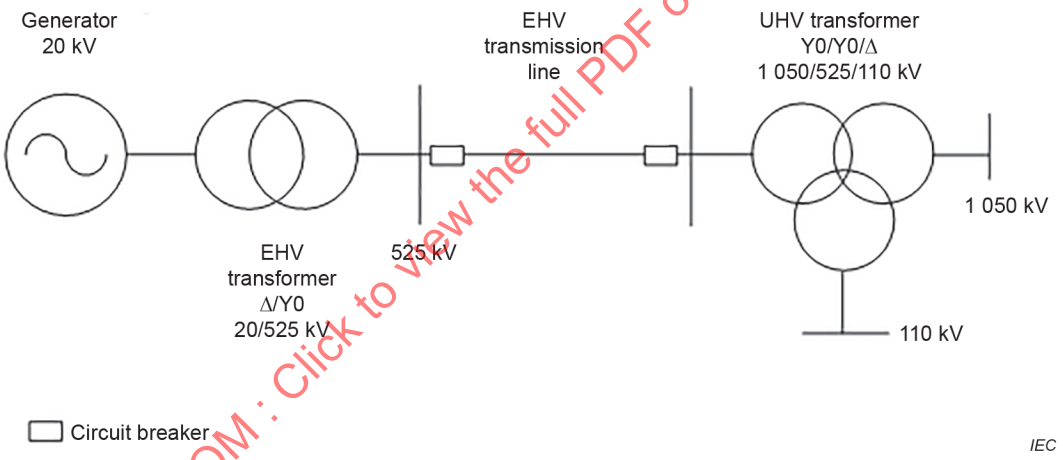


Figure A.2 – Circuit for test of UHV transformer with voltage increasing from zero

A.5.4.12 Test of UHV AC transmission line with voltage increasing from zero

a) Purpose

This test is performed in Jindongnan-Nanyang-Jingmen UHV AC pilot transmission project. The main purposes include the following:

- to examine the insulation performance of the UHV transmission line;
- to verify the compliance of the V-A characteristic of the UHV shunt reactor with design requirements;
- to carry out the secondary voltage phase-check of relevant VTs;
- to check the phase and amplitude of the secondary current circuit of relevant relay protection devices.

b) Method

This test is carried out in an isolated power grid, which includes a power generator, step-up transformer, EHV transmission line, UHV transformer, and UHV transmission line. Prior to the test, the simulation analysis on the self-excitation issue should be done and necessary countermeasures such as putting into enough shunt reactors should be taken to avoid the self-excitation risk. During the test, the voltage of the head or the end terminal of UHV transmission line is gradually increased to the maximum voltage.

A.5.4.13 Loop closing (interconnecting)/opening (splitting) test

a) Purpose

This test is performed for all UHV AC stations with newly constructed UHV transmission lines or transformers. The main purposes include the following:

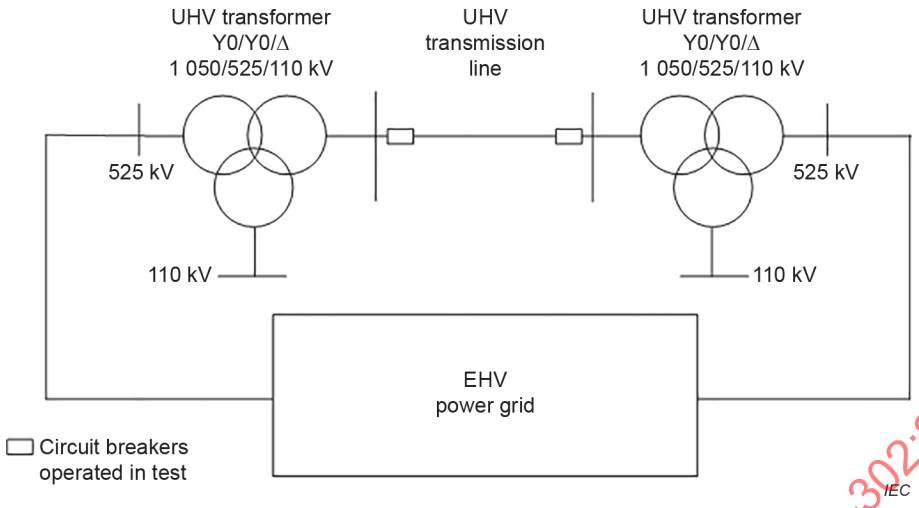
- to examine the adaptability of setting-values for the synchronous device of the circuit-breakers;
- to monitor the influences of loop closing (interconnecting)/opening (splitting) on the system voltage and power;
- to check the phase and amplitude of the secondary current circuit of relevant relay protection devices.

b) Method

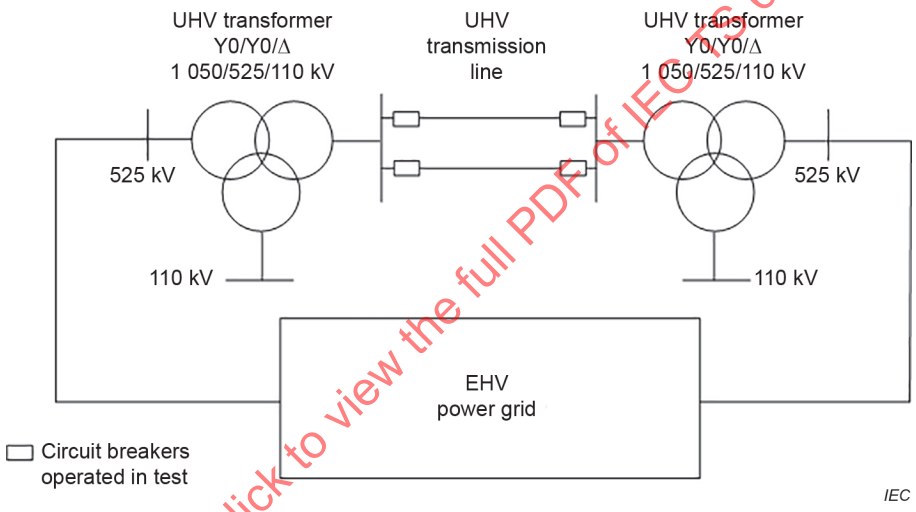
Each group of the involved circuit-breakers operates by three-phase closing and opening method and should be operated not less than once. Before the test, set the setting-values for the synchronous device of the circuit-breakers according to simulation analysis results. During the test, utilize the circuit-breakers at both sides of the UHV transmission line and the secondary side of the UHV transformer to do the loop closing (interconnecting)/opening (splitting) switching. By the operation that performed by loop closing (interconnecting)/opening (splitting) circuit-breaker of transmission line or transformer, the power grid of same or different voltage levels (such as system voltages of 1 100 kV and 550 kV) can run in/out of loop (synchronous interconnection) network .

For the case that the circuit-breaker at the secondary side of UHV transformer is not available for the test, the UHV line circuit-breakers can be applied instead. If the UHV transformer could not be energized from the secondary side in no-load mode for the commissioning system owning small short-circuit capacity or other reasons, the test can only be carried out with the secondary side circuit-breakers of the UHV transformer.

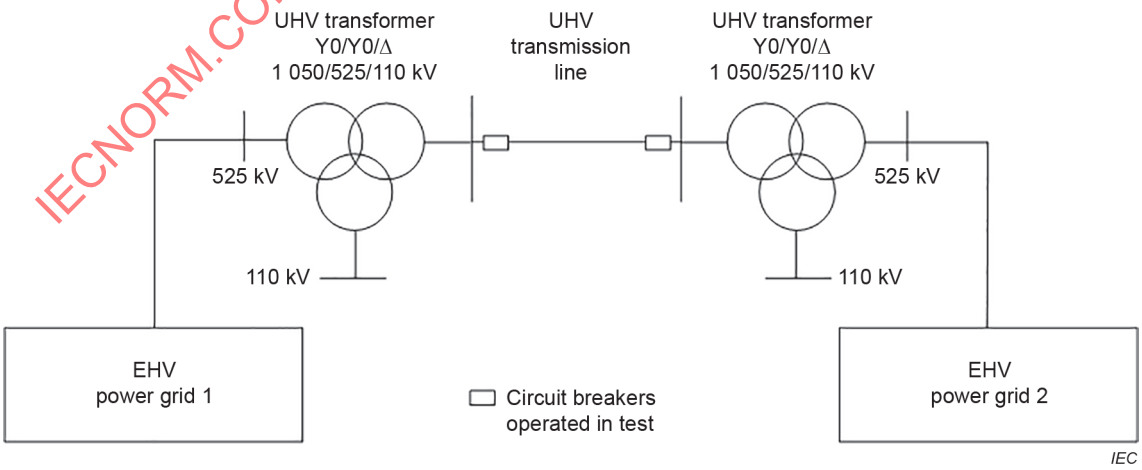
Figure A.3 shows 3 typical examples of circuit for loop closing (interconnecting)/opening (splitting) test operated by UHV transmission line circuit breakers.



A.3a – Loop closing/opening test operated by UHV transmission line circuit breakers to make the power grid of different voltage levels run in/out of loop network



A.3b – Loop closing/opening test operated by UHV transmission line circuit breakers to make the power grid of same voltage level run in/out of loop network



A.3c – Interconnecting/splitting test operated by UHV transmission line circuit breakers to make two power grids of same voltage level run in/out of synchronous interconnection

Figure A.3 – Circuit for loop closing (interconnecting)/opening (splitting) test operated by UHV transmission line circuit breakers

A.5.4.14 Artificial single phase to ground fault test

a) Purpose

The test is performed in Jindongnan-Nanyang-Jingmen UHV AC pilot transmission project and Huainan-Wannan-Shanghai UHV AC double circuit pilot transmission project. The main purposes include the following:

- to calibrate fault locating and check healthiness of protection relays;
- to verify the power system stability;
- to acquire the secondary-arc current and recovery voltage measurement data;
- to testify the correctness of single phase reclosing setting strategy for UHV transmission line circuit-breakers.

b) Method

Based on the simulation analysis results, select the ground fault location on the UHV transmission line to do the test. Previously, install the earthing device when the tested UHV transmission line is in maintenance state. Set the reclosing time for the line circuit-breakers according to simulation analysis results before returning the tested UHV transmission line to normal operation state. For single circuit line, the test is performed once, while for double circuit transmission lines, the artificial single phase ground fault test are performed with the lines in the following three states respectively: double circuit in operation, one circuit shut-down and one circuit in maintenance.

A.6 Measurement in system commissioning

A.6.1 General

Typical measurement items in system commissioning for UHV AC transmission projects are listed in Table A.3.

Table A.3 – Measurement items in system commissioning for UHV AC transmission projects

No.	Measurement items	Remarks
1	Transient voltage and current measurement	Mandatory
2	Electrical quantity measurement	Mandatory
3	Relay protection measurement	Mandatory
4	Harmonic measurement	Mandatory
5	Sound level measurement of transformer/reactor	Mandatory
6	Vibration measurement of transformer/reactor	Mandatory
7	DGA of transformer/reactor	Mandatory
8	Infrared temperature measurement (thermovision infrared scanning)	Mandatory
9	Power frequency electric and magnetic field measurement of substations/transmission lines	Mandatory
10	Audible noise measurement of UHV substations/transmission lines	Mandatory
11	Radio interference measurement for UHV substations and lines	Mandatory
12	Partial discharge monitoring in GIS/transformers	Mandatory
13	Ultraviolet corona measurement	Mandatory
14	Excitation inrush current measurement of UHV transformers	Mandatory
15	No-load characteristic measurement of UHV transformers	Optional
16	V-A characteristic measurement of UHV shunt reactors	Optional
17	Short circuit current measurement of UHV lines	Optional
18	Secondary arc current measurement of UHV lines	Optional

A.6.2 Measurement in system commissioning

A.6.2.1 Transient voltage and current measurement

Transient voltage and current measurement is conducted through the whole commissioning. The measuring positions include UHV transformer, UHV shunt reactor, tertiary reactor, tertiary capacitor and neutral point reactor. The transient voltage is measured by installing a capacitive voltage divider on the bushing end of the transformer, reactor and capacitor. The transient current is measured by applying the calliper current sensor on the secondary side of the CT of the transformer, reactor, capacitor and transmission line.

The measurement requirements and conditions are as follows:

- the sampling rate of the measuring equipment should not be less than 200 000 samples per second;
- the recording time should not be less than 0,5 s.

A.6.2.2 Electrical quantity measurement

Electric quantity measurement is conducted through the whole commissioning. The measurement parameters include power frequency voltage, power frequency current, active power, reactive power and frequency. The power frequency voltage is measured by taking the voltage signal from the secondary side of VTs for UHV transformer, reactor, capacitor and transmission line, etc. The power frequency current is measured by applying the calliper current sensor on the secondary side of the CT.

A.6.2.3 Relay protection measurement

All related relay protection and safety control devices for newly constructed UHV transformers, UHV shunt reactors, tertiary reactors, tertiary reactors, and UHV transmission lines need measurement during system commissioning. The measurement is carried out in the relay room of UHV substation by measuring the voltage and current signals at the secondary side of the VT and CT. The applied apparatus for measurement is Digital Phase Volt-Ampere Meter. The secondary current for checking phase should be greater than 10 mA.

A.6.2.4 Harmonic measurement

Harmonic measurement is conducted through the whole commissioning. The measurement is carried out in the relay room of UHV substation by measuring the voltage and current signals at the secondary side of the VT and CT. The applied apparatus for measurement is power quality analyser.

A.6.2.5 Sound level measurement of transformer/reactor

Before and after the energizing, UHV transformer and UHV shunt reactor are measured for sound level respectively. The background noise is measured before energized. After energized, sound level meter is applied to do the measurement by selecting several positions around the transformer.

A.6.2.6 Vibration measurement of transformer/reactor

Vibration measurement is carried out after UHV Transformer and UHV shunt reactor are energized. The measurement is performed by installing several vibration sensors on the oil tank walls of UHV transformers and UHV shunt reactors.

A.6.2.7 DGA of transformer/reactor

During the system commissioning, the UHV transformer, UHV shunt reactor and its neutral point reactor all need DGA measurement, in order to monitor whether there to be high temperature or discharge in the equipment. The measurement is performed before the equipment is energized and after finishing the energizing test for 24 h.

A.6.2.8 Infrared temperature measurement (thermovision infrared scanning)

Infrared temperature measurement is performed by thermovision infrared scanning imager. The measurement positions include the bushing and joint, box surface, cooler inlet and outlet of UHV transformer, UHV shunt reactor and its neutral point reactor, and also the outlet bushing joint of UHV GIS, and body and joint of tertiary reactor and capacitor. Record the power load, ambient temperature, humidity, measurement position and corresponding infrared diagram spectrum. The measurement is to check whether there is abnormal temperature rise of equipment in UHV substation after being loaded.

A.6.2.9 Power frequency electric and magnetic field measurement of substations/transmission lines

Power frequency electric and magnetic field measurement are carried out under the lead wire of UHV equipment in the substation, inspection walkway and road in the substation, outside the enclosure, sensitive points (residential houses, etc.) outside the substation, control building and relay room. Power frequency magnetic field measurement is also carried out near the UHV equipment in the substation.

For UHV transmission lines, the measurement contents include the lateral distribution of power frequency electric and magnetic field, and also include the power frequency electric and magnetic field of sensitive points.

The power frequency electric field is measured under the operation condition of UHV transmission line or substation (switching station) equipment with rated voltage.

The power frequency magnetic field is measured under the operation condition of UHV transmission line or substation (switching station) equipment being loaded.

A.6.2.10 Audible noise measurement of UHV substations/transmission lines

Audible noise measurement is conducted around the equipment of the substation, the boundary of the substation, outside the substation enclosure, sensitive points outside the substation and control room.

For UHV transmission lines, the measurement contents include the lateral distribution of audible noise and the audible noise of sensitive points.

The audible noise measurement of the substation is carried out under the operating condition of UHV transmission line or equipment being loaded.

The audible noise measurement for UHV transmission line is carried out under the operation condition with rated voltage.

A.6.2.11 Radio interference measurement for UHV substations and lines

Radio interference measurement is performed outside UHV substation and under the transmission line.

The measurement is conducted under the operation condition of UHV transmission line or equipment with rated voltage, and in fair weather.

A.6.2.12 Partial discharge monitoring in GIS/transformers

During system commissioning, partial discharge on-line monitoring or live detection are carried out for UHV GIS and transformer equipment when they are operating under rated voltage.

A.6.2.13 Ultraviolet corona measurement

The ultraviolet corona measurement is carried out under the operation condition of UHV transmission line or substation (switching station) equipment with rated voltage. The corona discharge of UHV equipment grading ring and busbar fittings is detected by ultraviolet imager.

A.6.2.14 Excitation inrush current measurement of UHV transformers

The inrush current is measured when charging the UHV no-load transformer from the primary (and secondary) side of UHV transformer. The sampling rate of the measurement equipment should not be less than 10 000 samples per second, and the recording time should not be less than 60 s. The range of the measurement instrument should be selected according to the simulation analysis results.

A.6.2.15 No-load characteristic measurement of UHV transformers

The no-load current and no-load loss measurement of the UHV transformer is carried out in the process of the test of UHV power transformer with voltage rising from zero, when the voltage at the primary side of UHV transformer reaches the rated voltage. The voltage, current and harmonic components of the primary, secondary and tertiary side of the UHV transformer are measured respectively.

A.6.2.16 No-load characteristic measurement of UHV transformers

The voltage and current of the UHV shunt reactor is measured during the test of UHV AC transmission line with voltage rising from zero.

A.6.2.17 Short circuit current measurement of UHV lines

During the artificial single phase to ground fault test of UHV transmission line, the short-circuit current flowing through the UHV circuit-breakers on both sides of the test line and the short-circuit current at the single-phase short-circuit grounding test point are measured.

A.6.2.18 Secondary arc current measurement of UHV lines

Secondary arc current is measured during the artificial single phase to ground fault test of UHV transmission line at the single-phase short-circuit grounding test point. Record the temperature, humidity, air pressure, wind speed, wind direction and other meteorological data of the test site.

Annex B
(informative)

Commissioning experiences in Japan

B.1 Overview

This annex describes the consideration of commissioning regulation and experience in Japan for UHV AC transmission systems.

First 1 100 kV transmission lines in Japan were constructed in 1999. The north-south UHV transmission line was built between Niigata and Yamanashi (root length 185 km). The east-west UHV transmission line was built from Nishi-Gunma Switching Station toward Fukushima (root length 245 km).

An UHV Equipment Test Station was also constructed (in the 550 kV Shin-Haruna substation), which contains the real size components of a 1 100 kV substation including 3 single-phase transformers (capacity of 3 000 MVA) and three sets of single-phase GIS (rated current of 8 000 A). After connecting the equipment to the grid in 1996, field verification tests (energizing including overvoltage and internal load current flowing tests) were carried out. This annex also introduces some test experiences in UHV Equipment Test Station.

B.2 Regulations

This annex includes the UHV regulations that can be considered from EHV regulations.

EHV regulation is defined by national guideline and/or the ministerial ordinance that establishes Technical Standards concerning Electrical Equipment (TSEE) in Japan. For non-statutory implementation items, cases are introduced by Electric Technology Research Association in Japan (ETRA) compared to type test, but implementation status and details differ depending on the utilities.

B.3 Pre-commissioning in Japan

B.3.1 General

Pre-commissioning test items are listed in Table B.1.

Table B.1 – Pre-commissioning items

Test items	
Combined test	Protection and control system test
	Instrument transformer test
	Switchgears and transformer test
Communication system test	Control and monitoring system test
	Protection and fault information system test
	Other monitoring and/or control system test

B.3.2 Combined test

B.3.2.1 Protection and control system test

a) Performance test of the protection relay

Each protection relay element should be implemented. The test voltage and current are applied from the test terminal of the protection device. The allowable error range is standardized by relevant standards in Japan.

b) Operation test of the protection relay

Both the main protection relay and the backup protection relay should be conducted. Measure the total operation time in the self-end test and in the end-to-end test.

- perform the test as close to actual operation as possible;
- for directional relays, check for malfunction in the opposite direction;
- for those with a trip lock circuit during out-of-phase, check the malfunction of the main relay due to out-of-phase.

c) Total test of protection and operation system

- Purpose

  To confirm a sound operation of protection device to trip associated circuit-breakers by relay trip command when a fault is detected in an electric circuit or an equipment of a substation.

- Inspection method

  Operate an associated relay device for each protection device and confirm that the concerned circuit-breaker breaks the current.

NOTE The operation of the relay is carried out by applying a test voltage/current from the test terminal of the protective device or by forcing the test button.

In case of end-to-end test, the following items also should be conducted:

– the main protective relay operates normally due to a short circuit fault or earth fault in the protection zone;

– the backup protection relay operates normally due to a short circuit fault or earth fault outside the protection zone of the main protective relay.

- Criteria

  Normal operation of an associated circuit-breaker, a fault indicator, an alarm device, and an open/close indicator of the circuit-breaker.

B.3.2.2 Instrument transformer test

a) Polarity test

In the polarity test, it should be confirmed that the polarity is subtractive by DC method (inductive kick method) based on the ground side (+) for VT and the busbar side (+) for CT. However, if DC method (inductive kick method) is not possible, it may be conducted in the low voltage energizing test.

b) Measurement ratio test

For VT/CT, apply a voltage/current from the primary side to check that the instrument transformer has the specified voltage/current ratio.

c) Insulation resistance measurement test

Measure the insulation resistance of measurement devices circuit with an insulation resistance meter.

d) Resistance measurement test

Check that the measured resistance value is appropriate compared to the total value of VT/CT secondary winding resistance plus control cable resistance calculated from control cable thickness and installation length plus input converter DC resistance. Make sure the circuit is healthy.

e) Instrument performance test

Indication error test should be performed for each instrument. Test voltage and current are applied from a test terminal, if possible. The tolerance should be within the range specified in national standard in Japan and in-house specification.

B.3.2.3 Switchgear and transformer test

a) Insulation resistance measurement

Measure the insulation resistance of operation circuit, control circuit, and auxiliary circuit with an insulation resistance meter.

b) Operation test

Open/close operation for switchgear and OLTC operation for transformer are performed without any problem with equipment.

c) Sequence, interlock test

Check that the sequence and interlock operation is normal between the circuit-breaker and the disconnector/earthing switch. Make sure that the wiring is correct and same as relevant circuit diagrams and drawings. The sequence test should be performed including external circuit conditions such as interlock.

d) Test on interlock between CB and HSES

Check the interlock between the circuit-breaker and HSES to verify the control circuit and mechanism:

- operation of HSES is only allowed under the relevant CB in open state;
- operating sequence test of HSES for closing and opening operations with variation in time between energizing of closing circuit and opening circuit under energized conditions of main circuit is recommended in order to verify the effectiveness of the interlock.

NOTE Clause A.2 of IEC 62271-112:2021 describes typical operation sequence and time chart of the relationship between the transmission line circuit-breakers that interrupt the fault current and the HSES.

B.3.3 Communication system test

B.3.3.1 Control and monitoring system test

a) Purpose

To confirm that correct operation and indications are given at remote control centre, circuit-breakers and OLTC in substation should be operated by remote control centre in accordance with the interpretation of TSEE (i.e., the document specifying technical requirements of TSEE).

b) Inspection method

- Circuit-breaker

  Remotely open and close the circuit-breaker at the substation from a control station, etc., and check the correct operation and switching status of the equipment.

- OLTC

  Remotely control the OLTC from a control station, etc., and check the tap changeover function and state change display.

c) Criteria

- Circuit-breaker

  The circuit-breaker operates properly and switching status display appears correctly.

- OLTC

  The OLTC operates properly and the status change display is correct.

B.3.3.2 Protection and fault information system test

a) Purpose

To confirm that correct alarms or status indications are correctly displayed if an abnormality occurs in equipment installed at a substation in accordance with TSEE.

b) Inspection method

Operate the protective relay or alarm device (intentional manual operation or change in set value) and check the alarm and display.

c) Criteria

Alarms and fault indications are displayed correctly.

B.4 System commissioning in Japan

B.4.1 General

System commissioning test items are listed in Table B.2.

Table B.2 – System commissioning items

Test items	
Energizing test	Energizing test of UHV switchgears and busbar
	Energizing test of no-load power transformers
	Energizing test of tertiary connected reactors
	Energizing test of tertiary connected capacitor
	Energizing test of UHV busbar shunt reactors
	Energizing test of no-load UHV transmission lines

B.4.2 Energizing test

B.4.2.1 Energizing test of UHV switchgears and busbar

It should be confirmed that a dielectric strength test of the substation equipment has been completed at manufactures' factory based on relevant standards in Japan, in the document inspection of the factory test record.

In commissioning, the normal voltage to ground should be first applied for 10 min as energizing test of UHV switchgear on the newly installed switchgear such as circuit-breaker and disconnector. The normal voltage is a voltage applied between the main circuit and the ground in a normal operation state.

Monitor the test voltage while applying the voltage, and confirm that there are no abnormal changes.

During the energizing test, the following methods are often taken:

a) In the energizing test, the commercial power grid may be applied to configure the temporally test grid, and a new constructed or expansion equipment in the substation should connected to this in order to conduct an energizing test;

b) It is recommended that the temporally test grid is basically constructed with a circuit-breaker of two sections and a shortened protection relay operation time settling value;

c) From the viewpoint of “the supply reliability", "restriction of test date and time zone" and "operation of complicated system operation and relay setting change", it may be also considered to choose a circuit-breaker of a section and a configuration to shorten the time limit value of protection relay operation. The implementation should be decided after discussion with the relevant sections;

d) If this is the case for an undesired system configuration that may cause abnormal voltage, the configuration of the test grid should be determined based on prior studies such as system analysis as necessary;

e) The energizing test is performed step by step in order from the power supply side equipment (for example, the power supply side switchgear, transformer, load side switchgear, etc.). The following operation is conducted during consisting the test grid in order to avoid the occurrence of abnormal voltage:

- Closing

  Step by step from the power supply side and spend it sequentially (including a parallel circuit).

- Opening

  Step by step from the lower voltage side and spend it sequentially.

B.4.2.2 Energizing test of no-load power transformers

Energizing test of no-load power transformers is performed according to the procedure and method described in B.4.2.1 with the following addition.

After completing the energizing test, measurement in B.5.2.2 and B.5.2.3 should be conducted.

During this test, measurement in B.5.2.1 may be implemented as optional.

B.4.2.3 Energizing test of no-load UHV transmission lines

a) Document inspection (for all insulators)

- Verify that there is no flashover or dielectric breakdown during the water injection breakdown voltage test in type test based on national standard in Japan;
- Confirm that the product has the same performance as the products that have passed the type test by referring to the “factory test report” of the insulator.

b) On-site inspection (energizing test)

Apply normal voltage for 10 min between a main electric circuit and the ground, and measure the voltage at the head terminal and the end terminal of the transmission line.

c) Criteria

- Documents inspection

  An insulator has the predetermined dielectric strength.

- On-site inspection

  There is no abnormality in insulation.

B.5 Measurement in system commissioning in Japan

B.5.1 General

Measurement items in system commissioning are listed in Table B.3.

Table B.3 – Measurement items in system commissioning

No.	Test items
1	Transient voltage and current measurement
2	Instrument transformer circuit measurement
3	Relay protection measurement
4	Audible noise measurement
5	Vibration measurement
6	DGA
7	Infrared temperature measurement
8	Power frequency electric and magnetic field measurement of substations
9	Power frequency electric and magnetic field measurement of transmission lines
10	Radio interference measurement of transmission lines
11	Moisture content measurement related to humidity sensitive equipment
12	Partial discharge monitoring in GIS/transformer
13	Measurement of transformer/reactor related to oil flow electrification

B.5.2 Measurement in system commissioning

B.5.2.1 Transient voltage and current measurement

a) Transformer inrush current measurement

This measurement may be performed as a reference, when a new model or a first commercial application is applied to either transformer or protection relays are introduced. Using a remote operation device or a monitor function of a protection relay, fine operation of a current differential relay locking function may be tested for an inrush current caused by an excitation of main transformer from the primary side or secondary side circuit breaker. In addition, measurement and collection of inrush current waveform data should be implemented.

Figure B.1 shows an example of circuit of that measurement. Inrush current and voltage were measured in 1 100 kV side test area by secondary side 550 kV circuit-breaker closing. The close operations of 550 kV circuit-breakers were carried out under the conditions of with and without pre-insertion resistor. Transferred surge voltage on main circuit by this inrush was also measured.

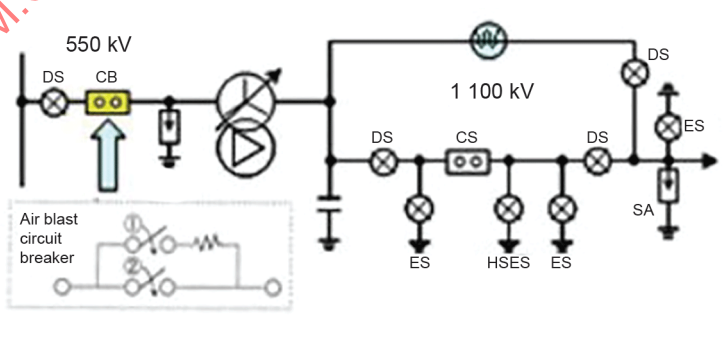


Figure B.1 – Circuit for transient voltage and current measurement

B.5.2.2 Instrument transformer circuit measurement

a) Voltage measurement and sense confirmation

After the completion of trial energizing, measure each phase of voltage in the same circuit at the test terminal of the protection and control device connected to the VT secondary circuit, and confirm that there is no abnormality in the voltage sense. At the same time, confirm that the measured value of the protection and control device is normal. During trial energizing, partial discharge measurement of GIS and transformer, surge arrester leakage current measurement, etc., are carried out.

b) Current phase measurement and CT secondary circuit polarity confirmation

Measure the current at the test terminal of the protection and control device connected to the CT secondary circuit of the equipment under test and confirms that there is no abnormality in the current ratio. At the same time, the current phase should be measured with reference to the VT secondary voltage to confirm that there is no error in the input polarity to the protection and control device. As for the actual power flow required for the measurement, phase modifying equipment load, transformer tap difference, etc., if these are not possible, connect the commercial grid and the equipment under test to be energized.

c) Load measurement of busbar VT secondary circuit and voltage measurement indicated value confirmation

Measure voltage, current and phase difference at VT secondary output terminals and branch to reactive power control (VQC) and busbar voltage telemeter (TM) converter in the normal busbar configuration to determine the VT ratio error correction settling value of VQC and TM. Based on this, the correction value should be calculated and this setting should be input, and it is confirmed that the busbar voltage measurement display value is normal.

B.5.2.3 Relay protection measurement

It is determined that there is no abnormality based on the result of the current phase measurement. Hence the current differential relay may introduce multiple CT secondary circuits, confirm that the difference current is below the allowable value and is normal.

B.5.2.4 Harmonic measurement

Harmonic measurement is not normally performed during commissioning in Japan.

B.5.2.5 Sound level measurement

Noise measurement of the transformer/reactor is not performed. Depending on regional regulations, audible noise in substation boundary may be measured (see B.5.2.11).

B.5.2.6 Vibration measurement of transformer

Vibration measurement is not performed because the rated capacity of the cooling motor is small enough to meet domestic regulations.

B.5.2.7 DGA of transformer

It is carried out at any time during installation, after oil lubrication, after a dielectric test, during a voltage test, or immediately after a temperature rise test. In addition, there are cases where the maintenance test is carried out after the start of operation in the first month, the third month, the sixth month, the first year, and the like.

B.5.2.8 Infrared temperature measurement (depends on utilities)

Infrared temperature measurement is not normally performed in Japan, instead inspection by terminal torque check and contact resistance measurement are implemented.

Infrared temperature measurement may be conducted as a maintenance test every year in some cases. Instead, fasten torque check or contact resistance measurement is commonly conducted.

a) Fasten torque check

For the main circuit clamping terminal, a method of confirming the soundness of the connection by an inspection record of fasten torque of bolts at the time of construction is taken.

b) Contact resistance measurement

In particular, the clamp terminal may confirm by contact resistance measurement that the contact resistance value does not exceed the rated resistance value of the down leads line.

B.5.2.9 Power frequency electric and magnetic field measurement of substations

a) General

Compliant with the electromagnetic health risk assessment by the World Health Organization (WHO) and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines set forth by ICNIRP.

NOTE 1 EMF health risk assessment (WHO):

Electric fields are considered not to cause health problems for ordinary people to live a normal life. Regarding the effects of high-level magnetic fields on health in the short term, the mechanism by which human nerves and the like are stimulated has been elucidated, and guidelines should be adopted based on scientific grounds which were established to protect this.

NOTE 2 ICNIRP guidelines:

Magnetic field to the general public at commercial frequencies should not exceed 200 μT (50, 60 Hz).

b) Magnetic flux density measurement

- Purpose

  To confirm that the magnetic flux density at the substation site boundary conforms to TSEE and the interpretation.

- Inspection method

  Confirm that the magnetic flux density at the boundary of the substation is below the criterion based on the magnetic flux density review document.

- Verify by visual inspection that the equipment is installed as shown in the cross-sectional plan view of the equipment layout used in the magnetic flux density review document. The distance from the substation boundary and the interphase distance in the magnetic flux density review document should be confirmed by actual measurements or drawings.

- Criteria

  The magnetic flux density should not exceed 200 μT.

c) Example of electrostatic induction field in the vicinity of the UHV bushing above the ground at certain height.