

A Review Comprehension: Guideline for Testing of HV, EHV and UHV Substation Equipment

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Abstract - Substations are important part of a power system it helps in transmission and distribution of electrical power system. A substation receives power from generating station by transmission line and further delivers electrical power through feeder and feeders are used to send the power in different areas. Substation main function is to receive energy from generating end transmit at high voltage for economic and reliable supply further reduce the voltage to a value appropriate for local distribution in distribution substation.

As per IS and IEC standard this paper covers the important equipment functions & their Testing in sub-station. Basically, sub-station consists of power transformer, circuit breakers, Isolators, Current Transformer (CT), Potential Transformer (PT), Insulators, Lightning Arrester, etc. We have discuss different types of Testing such as Power transformer testing, Current Transformer (CT) testing, Potential Transformer (PT) testing, Circuit breaker testing, Lightning Arrester (LA) testing and Insulator testing. The main aim is to review test according to IS and IEC standards for various equipment tests for improving reliability and to reduce faults chances in future.

Key Words: *Substation Equipment, Testing, IS and IEC standards.*

I. Introduction

Testing and commissioning of Electric substation equipment is essential to the start newly electrical system for the first time, considering its size, type of new installation, equipment used, ratings, etc. It is a very special and important for facing some unique challenges to electrical person. Inexperience and poor planning will result in delays for start newly installation which can lead to expensively product losses. So to start any project of substation installation the important thing is planning and preparation, from Engineering to commissioning and start up. It provides safety by going through procedure of testing and commissioning for all the Electrical system component. This paper also offers useful guidelines on what to do when things go wrong during this phase and selection of new equipment and what tests are performed before selection of equipment.

II. Basics of testing and commissioning

A. What is Testing and Commissioning?

Here, Testing is process to test various equipment according to their functions and specifications to prove its conformity before installation for electrical system safety and reliability.

Commissioning is defined as a process of achieving, verifying, and documenting that the performance of systems, and bring together to meet its definite objectives and criteria according to its quality.

B. What is need of Testing and Commissioning?

To check performance of equipment, specification, to maintain reliability of electrical system and safety. All the tests are performed before installation.

After performing various tests, checking the specifications, connections and completing the installation, we need to charge the line in which the data is verified as per specific standards.

III. Testing methods for equipment

A. Type test

Test carried out to prove conformity with their specifications these are intended to prove general qualities & design of a given type of manufactured item. Type testing is testing to determine whether a product or system matches with the requirements which is specified. Beyond simple conformance other requirements for efficiency, meeting rules or standards may apply.

B. Routine test

Test carried out on each part or item manufactured to check parameters which are likely to vary during production is termed as routine test. In case of mass production, there will be some of the test items that need to be implemented in order to make sure that the quality matches with the given samples. It is conducted on each product manufactured to confirm proper manufacturing of each and every units. This test is essential to be performed on each unit before dispatching the product to site. This tests are intended to check the quality of the individual test unit.

These tests are done to ensure the reliability of test object and consistency of the material used in their manufacture.

C. Acceptance test

Tests are carried out on samples taken at random from offered lot of manufactured items for the purpose of acceptance of lot. Acceptance and maintenance testing is done for high voltage projects such as substation construction, transmission and distribution projects, maintenance, labor support services, overhead and underground system. Acceptance tests verifies the product and actually solves the problem it was made to solve. This can best be done by the user (customer), for instance performing his/her tasks that the Equipment assists with. If the Equipment passes all these tests, then it is accepted to replace the previous solution. This acceptance test can sometimes only be done properly in production, especially if you have anonymous customers (e.g. ABB Circuit breaker). Thus a new feature will only be accepted after days or weeks of use. In short acceptance test is nothing but quality assurance.

IV. Various equipment in substation and their testing

A) *Lightening arrester (LA)*^[2]

Test Performed – Type Test

Standard - IS 3070 and IEC 6009-4 [See Table 1]

1. Insulation withstand test – To demonstrates the ability of the arrester housing to withstand voltage stresses under dry & wet conditions
2. Residual voltage test – To demonstrate the protective level of arrester.
3. Long duration current impulse withstand test – To Demonstrates the ability of the resistor energy to withstand possible dielectric & energy stresses without puncture or flashover
4. Operating duty test – To demonstrate the thermal stability of the arrester under defined conditions.
5. Test Arrester disconnectors – To demonstrate correct operation of the disconnectors.
6. Current Distribution Test for Multi-Column – To determine the current through each column of parallel resistor when there is no electrical connection between columns.
7. Partial discharge test – Measures the internal partial discharge.

Test Performed – Routine test

1. Residual voltage test – To demonstrate the protective level of arrester.
2. Partial discharge test – Measures the internal partial discharge.

3. Current Distribution Test for Multi-Column – To determine the current through each column of parallel resistor when there is no electrical connection between columns.
4. Seal leakage test – To determine the integrity of the arrester seals.
5. Measurement of reference voltage – To measure value within a range specified by manufacturer.

Test Performed – Acceptance test

1. Residual voltage test – To demonstrate the protective level of arrester.
2. Measurement of power frequency voltage on complete arrestors – To measure value within a range specified by manufacturer. Short Time Withstand Current & Peak withstand Current Test – To Prove capability of the disconnectors or earthing switches to carry the rated peak withstand current and the rated short time withstand current
3. Operation Under Severe Ice – To Prove satisfactory operation and mechanical endurance.
4. Operation at Temperature – To Prove satisfactory operation at minimum and maximum ambient air temperature.

Test Performed – Routine test

1. Power Frequency Voltage Dry Withstand test of main circuit – To Verify the insulation level including withstand test at power frequency voltages on auxiliary equipment.
2. Voltage test on control and auxiliary circuits – To Verify the insulation level of control and auxiliary circuits.
3. Measuring of the resistance of main circuit – To Measure resistance & confirm that it does not exceed type test value.
4. Mechanical Operation Test – To ensure that disconnectors / earthing switches comply with operating conditions at rated, maximum and minimum supply voltages.

Test Performed – Acceptance test

1. Partial Discharge Test – To Measure the internal partial discharge.
2. Power Frequency Voltage Dry Withstand test of main circuit – To Verify the insulation level including withstand test at power frequency voltages on auxiliary equipment.

Note: Table – 1 shows the maximum Withstand Voltage and protection level of Lightning Arrester in kilo-Amperes (KA).

Table - 1

Maximum Protection Level of Lightning Arresters				
Rated Voltage KV	Step current Protection Level at 10 KA	Lightning Impulse Protection Level		Switching protection Level at 1 KA
		5 KA	10 KA	
0.175	3.0	-	-	-
0.280	3.5	-	-	-
0.500	4.5	-	-	-
0.66	6.0	-	-	-
1.00	9.0	-	-	-
3	12	10	10	-
4.5	18	15	15	-
6	24	20	20	-
7.5	30	25	25	-
9	35	30	30	-
10.5	40	35	35	-
12	45	40	40	-
21	80	75	75	-
24	95	85	85	-
27	105	95	95	-
30	110	105	100	-
36	130	-	115	-
54	200	-	175	-
57	210	-	185	-
60	220	-	195	-
66	240	-	215	-
84	310	-	275	-
90	330	-	295	-
96	355	-	315	-
102	380	-	335	-
108	400	-	355	-
114	420	-	375	-
120	440	-	395	-
132	485	-	435	-
180	665	-	590	-
186	685	-	610	-
198	730	-	650	-
216	795	-	710	-
330	900	-	800	660
360	975	-	850	720
390	1050	-	900	780
600	1565 (20 KA)	-	1375	1230 (at 2 KA)
612	1595 (at 20 KA)	-	1400	1255 (at 2 KA)
624	1630 (at 20 KA)	-	1430	1280 (at 2 KA)
636	1660 (at 20 KA)	-	1455	1305 (at 2 KA)

B) Isolator and Earth (Double break, Single break type and Knee type) [3]

Test performed - Type test

Standard - IEC 60129 and IS 9921 [See Table -2]

1. Dielectric Tests – To verify the insulation level including withstand tests at power frequency voltages on auxiliary
2. Temperature Rise Tests – To prove that temperature rise of any part does not exceed the limit.
3. Short Time Withstand Current & Peak withstand Current Test – To Prove capability of the disconnectors or earthing switches to carry the rated peak withstand current and the rated short time withstand current

4. Operation Under Severe Ice – To Prove satisfactory operation and mechanical endurance.
5. Operation at Temperature – To Prove satisfactory operation at minimum and maximum ambient air temperature.

Test Performed – Routine & Acceptance test

1. Power Frequency Voltage Dry Withstand test of main circuit – To Verify the insulation level including withstand test at power frequency voltages on auxiliary equipment.
2. Voltage test on control and auxiliary circuits – To Verify the insulation level of control and auxiliary circuits.
3. Measuring of the resistance of main circuit – To Measure resistance & confirm that it does not exceed type test value.
4. Mechanical Operation Test – To ensure that disconnectors / earthing switches comply with operating conditions at rated, maximum and minimum supply voltages. [3]

Note: Table - 2 shows the Rated Lightning Impulse withstand voltage and Rated power-frequency withstand voltage in kilo-volts (KV).

Table - 2

Rated voltage KV (rms)	Rated lightning impulse withstand voltage KV (peak)				Rated power-frequency withstand voltage KV (rms)			
	To earth and between poles		Across the isolating distance		To earth and between poles		Across the isolating distance	
	Ind oor	Outd oor	Indo or	Outd oor	Ind oor	Outd oor	Indo or	Outd oor
4.76	60	-	70	-	19	-	21	-
8.25	75	95	80	105	26	35	29	39
15	95	-	105	-	36	-	40	-
15.5	110	110	125	125	50	50	55	55
25.8	125	150	165	165	60	70	66	77
38	150	200	220	200	80	95	88	105
48.3	-	250	275	275	-	120	-	132
72.5	-	350	385	385	-	175	-	195

C) Circuit Breaker (SF₆ Circuit Breaker, Vacuum circuit breaker, Oil Circuit breaker, and Oil Circuit breaker.) [4]

Test Performed – Type test

Standard - IEC 62271 - 100

1. Dielectric Tests – To Check capability and characteristics of circuit breaker with combination of voltage & the duties.
 - i. Dry, wet power frequency.
 - ii. Lightning impulse voltage.
 - iii. Switching impulse voltage.
2. Radio interference voltage test – To Find out the radio interference voltage on pole of circuit breaker in both close and open position.
3. Measurement of resistance of the main circuit – To Record value of circuit resistance for circuit breaker for mechanical operations to be within specified limits.
4. Temperature rise test – To Ensure capability of the circuit breaker contents to carry rated normal current within specified temperature rise limit
5. Short time withstand current and peak – To demonstrate the absolute leakage rate not exceeding the specified permissible value. This test can be performed on individual components or sub individual.
6. Short circuit current making and breaking tests – To Check ability of the circuit breaker to clear the value of current on different tests duties in symmetrical and asymmetrical conditions as per provisions of IEC standard.

Test performed – Routine test and Acceptance test

1. Dielectric Tests on main circuit – To Check the dielectrics withstand capability of live terminals to live terminals and to earth in both close and open condition of circuit breaker
2. Dielectric Tests on aux. and control circuit – To Check the dielectrics withstand capability of auxiliary and control circuit of circuit breaker subjected to short duration (60 second) voltage withstand test for 2 kV.
3. Measurement of resistance of the main circuit – To Record value of circuit resistance for circuit breaker for mechanical operations to be within specified limits.
4. Tightness test – To Demonstrate the absolute leakage rate not exceeding the specified permissible value. This test can be performed on individual components or sub assembly.

D) Current Transformer ^[5]

Table – 3 and 4 and 4] Test Performed – Type test Standard - IS 2705 [See Table-3

1. Short time current test – To measure current density of winding with respect to rated short time current.

2. Temperature rise test – To know actual temperature rise in current transformer under loading conditions.
3. Lightning impulse test for current transformers for service in electrically exposed – To verify lightning impulse voltage withstand capacity of installation.
4. High voltage power frequency wet withstand voltage test on outdoor current transformer up to & including 245 kV – To verify power frequency voltage withstand capacity of external insulation.
5. Determination of error or other characteristics according to requirement of designation or accuracy class
 - 5.1 Current error – To measure the actual ratio against rated ratio of current transformation.
 - 5.2 Accuracy Class – To know the actual accuracy against rated.
 - 5.3 Burden – To measure the impedance of secondary circuit.

Test Performed – Routine test and Acceptance test.

1. Determination of error or other characteristics according to requirement of designation or accuracy class.
 - 1.1 Current error – To measure the actual ratio against rated ratio of current transformation.
 - 1.2 Accuracy Class – To know the actual accuracy against rated.
 - 1.3 Burden – To measure the impedance of secondary circuit.
2. Verification of terminal marking and polarity – To ensure correct marking and function of current transformer.
3. Power Frequency Dry withstand test on Primary – To verify power frequency voltage withstand capacity of primary winding (Between primary winding and earth).
4. Power Frequency Dry withstand test on Secondary Winding – To verify power frequency voltage withstand capacity of secondary winding (Between secondary winding and earth).
5. Over voltage inter turn test – To ensure inter turn insulation strength.

Note: Table – 3 and 4 shows reading of rated insulation level of Current Transformer for every voltage Levels in kilo-volts (KV).

Rated Insulation Levels of Current Transformer up to and Including 245 KV voltage level			
Nominal system Voltage KV (rms)	Highest system Voltage KV (rms)	Power Frequency Withstand Voltage KV (rms)	Lightning Impulse Withstand Voltage KV (peak)
0.60	0.66	3	-
3.3	3.6	10	20 and 40
6.6	7.2	20	40 and 60
11	12	28	60 and 75
15	17.5	38	75 and 95
22	24	50	95 and 125
33	36	70	145 and 170
45	52	95	250
66	72.5	140	325
110	123	185	450
		230	550
132	145	230	550
		275	650
220	245	360	850
		395	950
		460	1050

Rated Insulation Levels of Current Transformer for Highest voltage level 420 KV and above			
Nominal system Voltage KV (rms)	Highest system Voltage KV (rms)	Lightning Impulse Withstand Voltage KV (peak)	Switching Impulse Withstand Voltage KV (peak)
400	420	1175 1300 1425	950 1050 1050
525	525	1425 1550	1050 1175
765	765	1800 2100 2400	1300 1425 1550

E) Potential Transformer [6]

Test Performed – Type test.

Standard - IS 3156 [See Table - 5 and 6]

1. Verification of Terminal marking and Polarity – To ensure correct marking and function of voltage transformer.
2. Power frequency Dry withstand tests on Primary – To Ensure Power frequency voltage withstand capacity of primary winding & insulation.
3. Power frequency Dry withstand tests on Secondary Winding – To Ensure Power frequency voltage
4. Withstand capacity of Secondary winding & insulation.
5. Determination of error or other characteristics according to requirement of designation or accuracy class.

5.1 Current error – To measure the actual ratio against rated ratio of current transformation.

5.2 Accuracy class – To know the actual accuracy against rated.

5.3 Burden – To measure the impedance of secondary circuit.

6. Temperature Rise Test – To know actual temperature rise in voltage transformer under loading conditions.

7. Impulse voltage tests of voltage transformers for services in electrically exposed – To verify impulse voltage withstand capacity of primary winding insulation in services condition in electrically exposed installation.

Test Performed – Routine test and Acceptance test

1. Verification of Terminal marking and Polarity – To ensure correct marking and function of voltage transformer.
2. Power frequency Dry withstand tests on Primary – To Ensure Power frequency voltage withstand capacity of primary winding & insulation.
3. Power frequency Dry withstand tests on Secondary Winding – To Ensure Power frequency voltage withstand capacity of Secondary winding & insulation.
4. Determination of error or other characteristics according to requirement of designation or accuracy class.
 - 4.1 Current error – To measure the actual ratio against rated ratio of current transformation.
 - 4.2 Accuracy class – To know the actual accuracy against rated.
 - 4.3 Burden – To measure the impedance of secondary circuit.

Note: Table – 5 and 6 shows the reading of rated insulation level of Current Transformer for every voltage Levels in kilo-volts (KV).

Table – 5 and 6

Rated Insulation Levels of Potential Transformer for Highest voltage level 420 KV and above			
Nominal system Voltage KV (rms)	Highest system Voltage KV (rms)	Lightning Impulse Withstand Voltage KV (peak)	Switching Impulse Withstand Voltage KV (peak)
400	420	1175 1300 1425	950 1050 1050
525	525	1425 1550	1050 1175
765	765	1800 2100 2400	1300 1425 1550

Rated Insulation Levels of Potential Transformer up to and Including 245 KV voltage level			
Nominal system Voltage KV (rms)	Highest system Voltage KV (rms)	Power Frequency Withstand Voltage KV (rms)	Lightning Impulse Withstand Voltage KV (peak)
0.60	0.66	3	-
3.3	3.6	10	20 and 40
6.6	7.2	20	40 and 60
11	12	28	60 and 75
15	17.5	38	75 and 95
22	24	50	95 and 125
33	36	70	145 and 170
45	52	95	250
66	72.5	140	325
110	123	185 230	450 550
132	145	230 275	550 650
220	245	360 395 460	850 950 1050

5. Measurement of insulation resistance – To check insulation strength.
6. Dielectric test –
 - 6.1 Separate source AC – To verify power frequency withstand capacity of winding (Winding to other winding and earth).
 - 6.2 Induced over voltage – To verify power frequency withstand capacity of winding (phases to earth and other winding).
7. Test on on-load tap changer where appropriate – To ensure proper operation of OLTC.
8. Buchholz Relay (BR) test – To check air injection test in Buchholz relay
9. Fans – To check oil valves when activate oil temperature circuit.

Note: Table – 7 shows reading of Rated Withstand Voltage for Transformer Windings with Every Voltage Level

Table – 7

Standard Insulation Level for All Insulators Up to 420KV and Including Rated Voltage and for Insulators for Non Effectively Earthed Systems above 72.5				
Highest system voltage KV (rms)	Visible Discharge Test KV(rms)	Dry and wet Power Frequency Withstand Test KV(rms)	Power Frequency Puncture Withstand on units KV(rms)	Impulse Voltage Withstand Test KV(rms)
3.6	3	21	1.3 times the actual dry flashover voltage the unit	45
7.2	5.5	27		60
12	9	35		75
24	18	55		125
36	27	75		170
52	36	105		250
72.5	53	140		325
123	88	230		550
145	105	275		650
245	154	460		1050
420	266	680		1425

F) Power Transformer [7]

Test Performed – Type test
Standard - IS 2026 [See Table - 7]

1. Measurement of voltage ratio and check of voltage relationship – To know correct voltage ratio of transformer at each tap and to check vector symbol.
2. Measurement of impedance voltage /short circuit impedance and load loss – To know copper loss and impedance voltage.
3. Measurement of no load loss & current – To know core loss and excitation current.
4. Measurement of insulation resistance – To check insulation strength.
5. Dielectric tests – To verify impulse voltage withstand capacity of insulation.
6. Temperature rise test – To check actual temperature risen in transformer under loading condition.
7. Test on on-load tap changer where appropriate – To ensure proper operation of OLTC.

Test Performed – Routine test and Acceptance test

1. Measurement of winding resistance – To know resistance of winding utilized.
2. Measurement of voltage ratio and check of voltage relationship – To know correct voltage ratio of transformer at each tap and to check vector symbol.
3. Measurement of impedance voltage /short circuit impedance and load loss – To know copper loss and impedance voltage.
4. Measurement of no load loss & current – To know core loss and excitation current.

G) Porcelain Insulators [8]

Test Performed – Type test
Standard IS – 2544 [See Table – 8 and 9]

1. Visual Examination – To check for any visual / surface defect.
2. Verification of dimension – To verify dimensions as per requirement and approved drawing.
3. Visible Discharge Test – To observe visible corona.
4. Impulse Voltage Withstand Test – To check ability of the insulators housing to withstand impulse voltage with positive & negative under dry conditions.
5. Wet Power Frequency Voltage Withstand Test – To check ability of the insulators housing to withstand power frequency voltage under Dry conditions.
6. Dry Power Frequency Voltage Withstand Test – To check ability of the insulators housing to withstand power frequency voltage under Dry conditions.

7. Temperature Cycle Test – To check the capability of insulators to withstand under thermal stresses.
8. Test for Mechanical – To check ability to withstand under specified falling load.
9. Puncture test – To check the capability to withstand the electrical stresses.
10. Porosity Test – To confirm non porous nature of product.
11. Galvanizing Test – To determine the uniformity of Zinc coating as well as its thickness over article.

Test Performed – Acceptance test

1. Verification of dimension – To verify dimensions as per requirement and approved drawing.
2. Temperature Cycle Test – To check the capability of insulators to withstand under thermal stresses.
3. Test for Mechanical – To check ability to withstand under specified falling load.
4. Puncture test – To check the capability to withstand the electrical stresses.
5. Porosity Test – To confirm non porous nature of product.
6. Galvanizing Test – To determine the uniformity of Zinc coating as well as its thickness over article. [8]

Test Performed – Routine test

1. Visual Examination – To check for any visual / surface defect.
2. Mechanical Routine Tests – To check capability to withstand mechanical stresses during normal conditions.
3. Electrical Routine Tests – To confirm to withstand Electrical stresses during normal conditions. [8]

Note: Table – 8 shows the number of insulator to be selected according to size and Table – 9 shows the standard Insulation Levels of Insulator for different Withstand Voltages.

Table – 8 and 9

Number of Post Insulator to be selected	
Lot size	Number of Post Insulator Units to be selected
Up to 500	To be agreed between the purchaser and the supplier
501 to 800	6
801 to 1300	8
1301 to 3200	10
3201 to 8000	14
8001 and above	20

Rated Withstand Voltage For Transformer Windings With Every Voltage Level		
Highest Voltage For Transformer KV rms	Rated short duration power frequency withstand voltage KV rms	Rated Lightning Impulse Withstand Voltage KV peak
1.1 3.6 7.2	3 10 20	- 20 and 40 40 and 60
12 17.5 24	28 38 50	60 and 75 75 and 95 95 and 125
36 52 72.5	70 95 140	145 and 170 250 325
123	185 230	450 550
145	230 275	550 650
170	230 275 325	550 650 750
245	325 360 395	750 850 950
300	395 460	950 1050
362	460 510	1050 1175
420	570 630	1300 1425

CONCLUSION

As per this review paper Testing and Pre-commissioning are done according to IS and IEC standard concludes that, after manufacturing of equipment the test which are held are necessary for selectivity of particular equipment. Every equipment has its different tests which is mentioned in paper. By performing successfully test on the particular equipment the chances of faults and maintenance for such equipment will be reduced, the life of equipment will be improve and also Testing improves the reliability and increases efficiency for continues flow of Power.

REFERENCES

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- [3] IEC 60129 and IS-9921 testing for Isolator and earth switch.
- [4] IEC 62271-100 standard testing for circuit breaker.
- [5] IS 2705 standard testing for current transformer.
- [6] IS 3156 standard testing for potential transformer.
- [7] IS 2026 Standard testing for power transformer.
- [8] IS 2544 Standard testing for porcelain insulator.