10

Testing of High Voltage A.C. Circuit-Breaker

Classification—Type tests/Routine test/Development test/Reliability test—Mechanical Tests—Temperature rise Tests—Dielectric Tests—Short time Current Tests—Basic Short-Circuit. Test Duties—Routine Tests—Special Tests—on EHV Circuit-breakers—Commissioning Tests—Summary

10.1. CLASSIFICATION OF THE TEST

The tests on high-voltage a.c. circuit-breakers can be classified as follows :

Development Tests

These are carried out on components, sub-assemblies and complete circuit-breaker during and after the development of the circuit-breaker. The designers and research scientist verify the effect of various parameters on the behaviour of circuit-breakers, by conducting development tests. Development tests are not specified in the standards.

Type Tests (Ref. Sec. 3.19)

These are conducted on first few prototype circuit-breakers of each type to prove the capabilities and to confirm the rated characteristics of the circuit-breaker of that design. Type tests are not conducted on every circuit-breaker. The tests are conducted in specially built testing laboratories. Type tests are performed as per recommendations of standards (IEC) or (IS).

Routine Tests

Routine tests are also performed as per the recommendations of the standards (IEC/IS).

Routine tests are conducted on each circuit-breaker. These are performed in the manufacturer's premises. Routine tests confirm the proper functioning of the circuit-breaker.

Reliability Tests

Type tests and Routine tests are conducted on new-circuits breakers under larboratory conditions. The performance of circuit breakers installed at site is affected by additional stresses such as variation in ambient temperature variations dust, humidity repeated operations, maintenance schedules etc.

Reliability tests are conducted to verify the reliability of the circuit-breakers under various stresses occurring in actual applications. Reliability tests can be conducted in specially built laboratories and also at site.

Commissioning Tests

These are conducted on the circuit-breaker after installation at site to verify the operational readiness and proper functioning.

The tests on low-voltage a.c. circuit-breakers are in Sec. 15.7.

Table 10.1

Summary of Type Tests on High Voltage A.C. Circuit-Breakers

Test	*Remarks*	*Ref. Sec*
1. No load mechanical operation test	No load operations to verify speed of travel, opening time, closing time. Carried out at 85% and 110% rated voltage of shunt trip release.	10.2.5
2. Mechanical performance tests (Endurance tests)	1000 close-open operations.	10.2.1

Test	*Remarks*	*Ref. Sec*
3. Temperature rise test.	Steady temperature of conducting parts and insulating parts measured for rated continuous alternating current.	10.2.2
4. Dielectric test—1.2/50 μs lightning impulse withstand—1 mm power frequency voltage withstand Dry and Wet.	Five consecutive shots of positive and then negative polarity. One minute p.f. withstand	12.6
5. Short-time current test.	Rated short-circuit current passed through closed breaker for 1 sec or 3 sec.	11.6
6. Short-circuit breaking and making, Basic. Short circuit test duties.	At 10%, 30%, 60% and 100% rated short circuit breaking current with specified operating sequence, and specified TRV.	11.7
7. Line charging current breaking tests.	Applicable for circuit breakers rated 72.5 kV. and above to be used for over head lines.	11.10
8. Cable charging current breaking tests.	Applicable to circuit-breaker intended for long cable network.	11.13
9. Single capacitor-Bank Breaking Tests.	Applicable or circuit-breaker to be used for capacitor switching.	11.12
10. Small inductive current breaking tests. Reactor Switching.	Applicable for circuit-breaker with shunt reactors, transformers, reactors, motors.	13.1 11.14
11. Out-of-phase switching.	Applicable to circuit breakers which may connect two parts made out-of-phase conditions.	11.11
12. Short-line Fault test.	Applicable to circuit-breakers rated above 52 kV and for overhead lines. These are in addition to basic short-circuit test duties.	11.9

10.2. TYPE TESTS

Type tests are the tests of one circuit-breaker on a first few circuit-breakers of each type made to the same specifications and having same essential details and would pass the identical tests. Type tests are conducted for the purpose of proving the rated characteristics of circuit-breakers. (Ref. Sec. 3.19)

Type test can be broadly classified in the following groups :

(*a*) Mechanical tests*

(*b*) Tests of temperature rise, millivolt drop test.*

(*c*) High voltage test (Dielectric tests).*

(*d*) Basic short circuit test duties.*

— Making test.

— Breaking tests.

— Operating sequence tests at 10%, 30%, 60%, 100% of rated breaking current with specified TRV conditions.

(*e*) Critical current tests.

(*f*) Single phase short-circuit test.*

(*g*) Short time current test.

* These are essential for certification of a.c. circuit breakers rated 145 kV and above in all cases.

In addition to these the following tests are recommended on circuit-breakers to be used in specific applications.

(*h*) Short line fault tests*
(*i*) Out-of-phase switching tests.
(*j*) Line-charging current-switching test.*
(*k*) Cable-charging current switching tests.
(*l*) Capacitive current switching tests.
(*m*) Small inductive current breaking tests.
(*n*) Reactor current switching tests.

Type tests are conducted on new circuit-breaker. Before conducting the type tests, sufficient information should be furnished to the testing authorities for identifying the circuit-breaker.

This information includes : assigned ratings, design principle drawings, reference standards, rated operating pressure/voltage of auxiliaries, support-structure etc. These details are included in the type tests report. After certifying the circuit-breaker by conducing type-tests, there should be no change in the design.

10.2.1. Mechanical Test (Endurance Tests)

The breaker should be in a position to open and close satisfactorily. In mechanical tests, the circuit-breaker is opened and closed several times (1000). Some operations (50) are by energizing the relay, remaining are by closing the trip circuit by other means. Mechanical tests on high voltage a.c. circuit breakers are conducted without current and voltage in the main circuit. Out of the 1000 operations, about 100 operations are mady by connecting the main circuit (contacts) in series with trip circuit.

No adjustment or replacement of parts is permitted during the mechanical tests. However, lubrication is permitted as per manufacturers instructions.

After the tests, the contacts, linkages and all the other parts should be in good condition and should not show any permanent deformation or distortion. The dimensions should be within original limits. During repeated operations of the circuit- breaker, the weaker parts in the assembly may fail. The circuit-breaker is then considered to have failed in the mechanical test. The tests are then to be repeated after improvement in the design and manufacture. Successful performance in Mechanical Endurance tests prove the adequacy of design and also good quality of materials and manufacture.

Though 1000 close-open cycles are specified in the standards, the manufacturer may conduct 10,000 or more operations to ascertain the reliability and for getting design data.

10.2.2. Temperature-Rise Tests

These are type tests to assign the normal current rating to the circuit-breaker (Ref. Sec. 31.9.4). Similar tests are conducted on other switchgear equipment such as isolators, bus-bars.

Alternating current of rated value and rated frequency is passed through a closed circuit-breaker, continuously till a steady temperature is attained. Readings of temperature of various conducting, insulating and structural parts are taken at an interval of one or half-an hour. When the steady temperature is reached, the maximum temperature rise of each part should be less than the permissible limit (Ref. Table 3.4). When a circuit-breaker in closed condition carries normal current the heat is generated in current-carrying parts due to $I^2 Rt$ loss. This heat is dissipated by conduction, convection and radiation. To maintain the temperature rise within specified limits, the $I^2 Rt$ losses should be reduced by increasing conductor cross-section using suitable low resistivity material, improving convection, conduction and radiation of heat.

The test set-up is illustrated in Fig 10.1. The current is obtained from special transformer which gives required continuous current at a low voltage (5 to 15 V a.c.) current is adjusted by regulation on primary voltage (240 or 440 V). The tests are either single phase or three phase. Single phase tests are permissible for outdoor circuit-breakers.

* These are essential for certification of a.c. circuit breakers rated 145 kV and above in all cases.

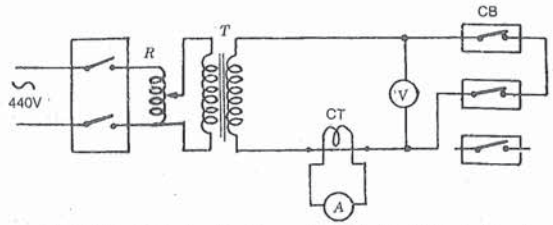

Fig. 10.1. (*a*) Test circuit—Temperature Rise Test (Single Phase)

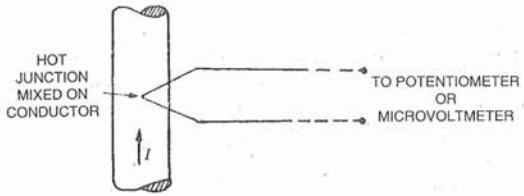

Fig. 10.1. (*b*) Measurement of Temperature.

The temperature is measured by means of Thermocouples. Thermocouple comprises a junctions of two dissimilar materials. The e.m.f. induced depends upon temperature difference between the hot junction and cold end. The hot junctions are fixed on the parts of circuit-breakers (Contacts, conductors, terminals, insulators etc.). The output of the thermocouples is measured by potentiometer or digital voltmeter. The temperature is calculated for the calibrated value (°C per millivolt).

Alternatively, temperature can be measured by self-resistance method or thermometers.

10.2.3. Measurement of D.C. Resistance

The D.C. resistance of main circuit of each pole of a circuit-breaker is of the order of a few tens of micro-ohms. The resistance of the pole tested for temperature rise provides the basis of comparison for all other poles of the same type. The resistance is measured by measuring d.c. voltage drop or by measuring resistance across terminals of each pole by means of a micro-ohm-meter.

10.2.4. Millivolt Drop Tests

The voltage drop across the breaker pole is measured for different values of d.c. currents. The voltage drop gives a measure of resistance of current carrying part and contacts.

The d.c. current should be more than 100 A and less than rated current of circuit-breaker. The resistance of breaker pole should be measured at ambient air temperature. The resistance is of the order of a few tens of micro-ohms.

10.2.5. No-load Operation Tests and Oscillographic and other records

The no-load operation tests include the following operations :

— Closing (C)
— Opening (O)
— Operating sequence (Ref. Sec. 3.19.8)

O—0.3 sec.—CO—3 min—CO (For rapid Auto-reclosure) and

O—3 min—CO—3 min—CO or

CO—15 sec.—CO. (For non-rapid autoreclosure).

No load tests are conducted prior to short-circuit tests. The following quantities are recorded on Oscillographs taken during the no-load test :

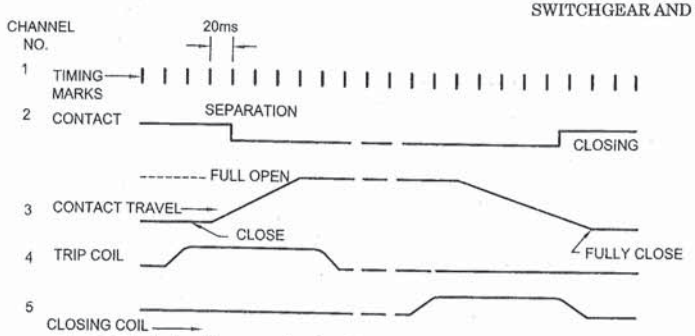

Fig 10.2 Typical oscillogram of no-load O.C. test taken on ultra-violet recorder.

— Travel of moving contact.
— Pressure of Quenching medium (*e.g.* SF_6 Gas)
— Instant of contact separation.....Ch. 2., Fig. 10.2
— Closing coil current.....Ch. 5.
— Contact touch.....Ch. 2.
— Timing Scale.
— Current in trip coil.

The no-load tests are carried out with following conditions :

With solenoid operated mechanisms tests are made with closing solenoid energized at both 105% and 85% of rated supply voltage of closing coil.

With spring mechanism, pneumatic mechanism and hydraulic mechanism, the shunt release (trip coil) should operate at 85% and 110% of rated supply voltage. The no-load tests indicate the functional readiness of circuit-breakers. The no-load characteristics should be indentical to the required characteristic.

The oscillographic records are generally obtained on multi-channel ultra-violet recorders (U.V. recorders). One channel is required for each quantity. The contact-travel is recorded by means of rectilinear potentiometer (travel recorder) connected suitably to the moving contact system.

10.2.6. Dielectric Tests

These are conducted to confirm the rated level of the circuit—breaker. The dielectric tests include power frequency voltage withstand tests and impulse voltage withstand tests (Further details in Ch. 12).

10.2.7. Basic Short-Circuit test Duties

These are performed in specially built short-circuit testing stations. These tests confirm the rated making capacity and rated breaking capacity of the circuit-breaker with reference to rated operating sequence. The basic short-circuit tests consists of the following five test duties :

Test duty 1	:	at 10% rated breaking current with d.c. component less than 20% with rated operating sequence for opening operation only.
Test duty 2	:	at 30% rated breaking current, with d.c. component less than 20% with rated operating sequence for opening operation only.
Test duty 3	:	at 60% rated breaking current with d.c. component less than 20% with rated operating sequence for opening operation only.
Test duty 4	:	at 10% rated breaking current with rated operating sequence.
Test duty 5	:	That is applicable for fast circuit breakers whose contact separation time is less than about 70 ms. This duty consists of rated operating sequence at 10% rated breaking current with specified d.c. component.

Details about Basic Short Circuit-Test duties are given in Ch. 11, Sec. 11.7.

10.3. ROUTINE TESTS (Ref. Sec. 10.9)

Routine tests are conducted on each circuit-breakers before dispatch. A routine test is defined as a test of every circuit-breaker made to the same specifications. The routine tests include the following tests :

(*a*) Mechanical operation tests
(*b*) Millivolt drop test, measurement of resistance
(*c*) Power frequency voltage tests at manufacturers premises
(*d*) Voltage tests on auxiliary circuits, control circuits.

Routine tests reveal the defects in the materials and construction of circuit-breaker. The result of routine tests confirm the quality of the circuit-breaker.

Mechanical Operation Tests

During routine testings five opening and five closing operations should be carried out at (*a*) minimum supply voltage and pressure (*b*) maximum supply voltage and pressure.

10.4. DEVELOPMENT TESTS

The circuit-breaker development and manufacture involves a very large number and variety of tests on individual items, materials sub-assemblies, units, poles and complete assemblies. Extensive testing is employed to ensure reliable equipment.

Development tests (Design tests) are necessary to verify the effect of various parameters on the performance. For example, to ascertain the effect of contact speed on breaking capacity, the circuit-breaker is tested repeatedly with change in contact speed. Before, the development of a circuit-breaker the arc-quenching principle is identified. The various parameters and their influence is theoretically predicated. Some special tests rigs are made for testing and measurement. Full scale prototypes are then manufactured. In this process, the designers use useful data available with the company. For example for design of the procelain, the necessary data are available from the catalogues of the manufactures of porcelain. For design of contacts the configuration can be derived from available designs of contact assemblies.

Each sub-assembly has certain functional requirement. For example, the contacts should give low resistance in closed condition, should not get deforming during mechanical operations, should not get welded during short-time current tests etc. Hence, to verify the capability of contact configurations, necessary development tests are conducted depending upon these functional requirements. Necessary modifications are made on the basis of test results. Pressure tests are conducted on porcelains, glassfibre tubes, etc. to test the leakage and the withstand pressure (Ref. Table 10.2).

10.5. RELIABILITY TESTS*

Type tests and routine test specified in the standards are conducted on new circuit breakers in clean and healthy condition. However the circuit-breaker installed at site is subjected to various stresses such as

— alternate variation of ambient temperatures
— extremely low temperatures
— extremely high temperatures
— rain moisture
— vibrations due to earthquakes
— dust, chemical fumes etc.
— frequent, switching in some cases
— overloads, over voltages etc.

Moreover, the circuit-breaker may not be maintained by skilled personnel at times. The reliability of circuit breakers is verified by conducting special reliability tests. For example the

* New standards are under publication.

circuit-breaker is subjected to extremely low temperatures created in climatic test chambers. After the tests the sealing rings and other parts are critically examined.

Based on large number of mechanical operation tests, short-circuit tests etc., the manufacturer recommends the maintenance practice to the followed for the circuit-breaker. Tables 10.2, 10.3 and 10.4 give a list about the variety of tests performed on the items, sub-assemblies and full assemblies of SF_6 circuit-breaker during and after the development.

10.6. COMMISSIONING TESTS

After the installation the circuit-breakers and protective gear are subjected to commissioning tests, are conducted on site to ensure proper assembly and operational readiness of the equipment. High accuracy is generally not expected in such tests. The tests facility available on site is also a deciding factor.

The commissioning tests include.

— mechanical operation tests.
— measurement of travel, simultaneous touching of contacts.
— measurement of insulation resistance, measurement of DC resistance of poles.
— pre-commissioning checks, SF_6 gas pressure, Vacuum Integrity.
— operation open the close
— checking of operation by energising the manual operating signal
— checking the operation by energising of relays etc.

Table 10.2 Unit Test on Single Sub-assemblies of SF_6 Circuit-breakers

	Pole	*Insulators*	*Castings*	*Gaskets*	*Spring*	*Capacitance*	*Control rods*
Pressure test	*	*	*				
Dimensional control	*	*	*	*	*		*
Visual check	*	*	*	*	*	*	*
Hardness			*	*	*		*
Dielectric strength	*	*					*
Tensile strength							*
Special tests	*	*	*	*	*		*
Test certifications	*	*	*	*	*	*	*

Table 10.3. Units Test on Sub-assemblies

	Control Unit	*Arc. Ext. chamber*	*Pole*	*Switch cubicle*	*SF_6 Gas system*	*Accessories*
Mech. operations	*	*	*	*		
Excess pressure		*	*	*	*	
Switching time	*	*	*	*		
Gas pressure		*	*		*	*
Minimum operating pressure		*		*		
Voltage drop		*	*			
Gas leakage		*		*	*	
Insulation test		*				
Operational control	*	*		*	*	*
Completeness	*	*	*	*	*	*
Leakage test		*	*		*	

Table 10.4. Test on Components of SF_6 Circuit Breaker

	Gas system	*Insulators*	*Sub-Assemblies*	*Arc Extinction chamber*	*Breaker pole*	*Complete Breaker*	*Cubicle*
Switching times				*	*	*	*
Travel measurement				*	*	*	
Min. Control voltage					*	*	*
Pressure test	*	*	*	*	*	*	*
Leakage	*		*	*	*	*	
Life expectancy			*	*	*		*
Durability		*	*	*	*	*	*
Climate tests		*	*	*	*	*	*
Icing tests				*	*	*	*
Current path resistance				*	*		
Noise measurement					*	*	
Earthquake effects					*	*	
Tensile strength		*					
Bending strength		*					
Sharp temperature drop		*					
Impulse voltage		*			*	*	
Power frequency voltage		*			*	*	
Switching over voltage					*	*	
Bias test					*	*	
Corona inception						*	
Radio interface voltage						*	
Terminal short circuit					*	*	
Short-time current					*	*	
Small inductive current					*	*	
Unloaded lines					*	*	
Phase opposition					*	*	

10.7. INSULATION RESISTANCE MEASUREMENT AT SITE

Insulation resistance is measured by means of Megohm-meter (Megger). The megger comprises a megohm—meter, and built-in d.c. generator. The minimum reading is zero and maximum is infinity. The scale is in megohms. The two terminals of megger arc connected across the insulation *i.e.* on the conductor and other to earthed body. The handle is rotated by hand or motor. The insulation resistance indicated by the pointer in megohms.

For h.v. switchgear, 1000 V or 5000 V (d.c.) megger is preferred. The insulation resistance of h.v. circuit-breaker is very high (above 1000 megohms). Refer Appendix E4)

Insulation resistance of control circuit trip circuit, relay circuit secondary circuit, etc., is a measured by means of 500 V megger. Value obtained should not be less than 1 megohm.

10.8. HIGH VOLTAGE POWER FREQUENCY WITHSTAND TEST (ROUTINE TEST)

Power frequency voltage withstand tests are routine tests. High voltage tests (as per the recommendation of standards) are conducted on each circuit-breaker. By such tests, the defective insulation or small creapage if any are brought to notice. Test Voltages are applied as follows : Aa, Bb, Cc, are terminals of poles and F is the Frame.

Test Condition No.	*Circuit-breaker Condition*	*Voltage applied to*	*Earthed connection to*
1.	Close	Aa Cc	BbF
2.	Close	Bb	Aa Cc F
3.	Open	ABC	abcf
4.	Open	abc	ABCF

10.9. ROUTINE TESTS OR CIRCUIT-BREAKERS

Routine Tests include the following :

1. Mechanical operation tests.
2. Measurement of resistance of main circuit of each pole.
3. Power frequency voltage withstand test on main circuit of each pole and the combination of poles and breaker-frame.
4. Voltage withstand test on auxiliary circuits.
5. Measurement of Insulation resistance of main circuits.
6. Measurement of Insulation resistance of auxiliary circuits.
7. Tests and checks after mechanical operation tests.

Routine tests are conducted on each circuit-breakers before dispatch. A routine test is defined as a test of every circuit-breaker made to the same specifications.

Routine tests reveal the defects in the materials and construction of circuit-breaker. The results of routine tests confirm the quality of the circuit-breaker.

On complete Circuit-breaker or Part of it.

Circuit breaker upto 132 kV may be tested with all the 3 poles assembled on frame and with mechanism assembled for the complete 3 phase circuit-breaker.

Mechanical operating tests should preferably be made on the complete circuit-breaker. However when circuit-breakers are assembled and shipped as separate units routine tests may be performed on components. Operating mechanisms and control cubicles shall be tested together with the circuit-breaker or with an appropriate dummy load.

10.9.1. Mechanical operating tests (Routine Test)

Mechanical operating tests are performed on 3 phase breaker on a part of it.

(*a*) at specified maximum supply voltages and pressure (if applicable)
   1. five closing operations
   2. five opening operations

(*b*) At specified minimum supply voltages and pressure (if applicable)
   1. five closing operations
   2. five opening operations

(*c*) At rated supply voltages and pressure (if applicable)
   1. five close-open operating cycles with the tripping mechanisms energized by the closing of the main contacts.

   2. moreover for circuit-breakers intended for rapid autoreclosing, five open-close sequences O—i—C where -i shall be not more than the interval specified for the rated operating sequence.

Measurements during mechanical Operation Tests.

For each required operating sequences the following measurements are :

— measurement of operating times :

— measurement of fluid consumption (if applicable)

If possible the time-travel diagram should be recorded.

Mechanically stressed auxiliary equipment should function correctly during and after the tests.

QUESTIONS

1. Distinguish between type tests, routine tests, development tests.
2. State the various type tests necessary or high voltage a.c. circuit breaker.
3. Fill in the gaps.
   (*a*) The contact resistance of circuit-breakers is of the order of.....
   (*b*) High voltages test include :
      (1) .....
      (2) .....
      (3) .....
   (*c*) Insulation resistance of H.V. circuit-breakers is more than.....
   (*d*) Routine tests are conducted on.....circuit-breaker.
   (*e*) Short circuit tests of current carrying parts for normal current should be less than.....
4. Describe the following (any two) :
   (*a*) Temperature rise test. (*b*) Millivolt resistance measurement.
   (*c*) Insulation endurance tests. (*d*) Mechanical endurance tests.
   (*e*) No load Mechanical tests. (*f*) Routine tests.
   (*g*) Type tests.
5. What is the difference between power frequency test and impulse voltage test ?
6. Explain the term Insulation Resistance and the procedure of measurement of the same.
7. Describe the procedure of conducting temperature rise test on a high voltage ac. circuit breaker. Draw a neat sketch of the test circuit. Explain the procedure of measurement of temperature rise.
8. State the various routine tests on High Voltage AC Circuit-breakers.
9. Describe the mechanical Operation tests on high voltage AC circuit-breakers for routine testing.
10. State the application of voltage under various breaker position during the routine power frequency voltage withstand tests on High Voltage AC Circuit breakers.