11

Short Circuit Testing of Circuit-Breakers

11.1. INTRODUCTION

In Chapter 9, we studied the difference between type tests and routine tests. The various tests performed on circuit-breakers according to Standard Specifications were briefly reviewed. The short-circuit tests come under Type Tests. The short-circuit tests and switching duty tests on circuit-breaker include :

(*a*) Breaking current tests.

(*b*) Making current tests.

(*c*) Short time current tests.

(*d*) Operating duty tests, Basic short-circuit Test Duties.

(*e*) Tests for small inductive currents.

(*f*) Test for short line faults (SLF).

(*g*) Tests for breaking capacitive currents.

(*h*) Capacitor switching.

(*i*) Out-of phase switching.

(*j*) Line charging current breaking tests.

(*k*) Cable charging current breaking test.

(*l*) Critical current tests (m) Inductive current tests.

Short-circuit test mentioned above are conducted to prove the ratings of the circuit-breaker. In addition, short circuit tests are performed for research and development. The modern EHV circuit-breakers are developed through experimental investigation of the problems of circuit-breaking *e.g.* arc extinction, current chopping, breaking of inductive current etc.

11.2. STRESSES ON CIRCUIT-BREAKER DURING SHORT-CIRCUIT TESTS

The short-circuits produce a severe stress on circuit-breakers. The circuit-breaker should be capable of withstanding the stresses. Short-time current test verify the capacity of the circuit-breaker to carry the specified short-circuit current for a duration of 1 sec or 3 sec. When short-circuit current is passed through the circuit-breakers, the contacts and current carrying parts are subjected to thermal stresses. The insulation in the vicinity of conductors is severly stressed. The poles and terminals experience electro-dynamic forces. The short time current tests verify the ability of the circuit-breaker to withstand temperature stresses and electrodynamic forces.

The making capacity test verify the ability of the circuit-breaker to close on short-circuit. As the circuit breaker closes on existing short-circuit, the current reaches a high value during the peak

of the first current loop. The electrodynamic forces between contacts and between poles reach a high value. The circuit-breaker should be capable of closing effectively contact welding and contact bouncing.

The breaking capacity tests verify ability the of the circuit-breaker to clear short-circuits. The operating mechanism and the interrupter should be able to perform their functions effectively. During the breaking operation, the operating mechanism is subjected to mechanical stresses. The contacts and current carrying parts are subjected to thermal stresses. The insulating and metallic materials in the neighbourhood of the arc are subjected to high thermal stresses. The part of the interrupter may be subjected to high pressure due to increase in pressure in the interrupter.

These stresses depend on the magnitude of fault current and the design of the circuit-breaker itself. In the post current zero period the contact gap is subject to transient recovery voltage. The severity of the voltage stresses depends upon the system configuration and the type of switching duty. *Short circuit testing is an experimental method for proving the ratings of the circuit-breaker and investigating the behaviour of circuit-breaker for research and development.*

The chapter is divided into three sections as follows :

Part A-Short Current Testing Plants.

Part B-Basic short-circuit Test Duties and Special Tests.

Part C-Indirect Tests.

The short-circuit testing plants are built specially and they provide the facility of short circuit testing. In Direct texts the breaker is subjected to direct short-circuit and results are analysed. In Indirect Testing, the capacity of complete breaker is ascertained by indirect test procedures.

Tests are conducted as per relevant standards.

PART A

11.3. SHORT-CIRCUIT TESTING PLANTS

There are three types of testing station :

1. Field type testing station.
2. Laboratory type testing station.
3. Composite testing station.

In field type testing power required for testing is directly taken from a large power system, the breaker under tests is connected in the system.

In laboratory type of testing the short-circuit generators provides the power for testing. In laboratory testing the breaker is tested directly or indirectly. When the capacity of the test plant is inadequate to test the breaker, indirect tests are performed to assess the behaviour of the circuit-breaker. There are several indirect methods of testing such a subsitution method, unit testing synthetic testing etc. A composite testing station is a combination of field type testing station and laboratory type testing station.

Layout of a Simple Short-circuit Testing Station*

The layout of a test plant for testing 11 kV/33 breakers up to 750 MVA is simpler and different from that of a large test plant for testing breakers up to, say 220 kV, 7500 MVA.

(*a*) **Description of a simple Test Plant** (Fig. 11.1)

The short-circuit power is supplied by speciality built *Short-cicuit Generators.* There are normally two or more generators though only one is shown in the figure. The short circuit generators

* Switchgear, testing and development station (STDS). Bhopal belonging to CPRI has a capacity of 1250 MVA can test circuit-breakers upto 12 kV. A very high capacity composite short-circuit testing station has been built a CRRI, Bangalore 1989. Breakers up to 420 kV, 62.5 kA can be tested.

are driven by three phase induction motor and the special type of excitation called impulse excitation is provided.

Series resistor and reactors are provided for adjusting the magnitude of short-circuit current and power factor.

The Master Circuit-Breaker has higher capacity than circuit breaker under test. In the event of failure of the circuit-breaker under test, the Master Circuit-Breaker opens and protects the circuit.

Making switch is a specially designed circuit closing device which can close at the desired moment and can withstand the making currents.

Transformers are used to get test voltages other than the generator voltage. The transformers are single phase units which can be connected in different ways to get several test voltages.

In addition to the above equipment there is equipment for

1. Measurement, record, control;
2. Sequence switch to obtain sequential operation;
3. Auxiliaries etc.

(*b*) **Short-circuit Generator and Drive Motor**

Short-circuit generators provide power to the circuit-breakers under test. The short-circuit generators must be capable of withstanding extremely high reactive power surges lasting for a short

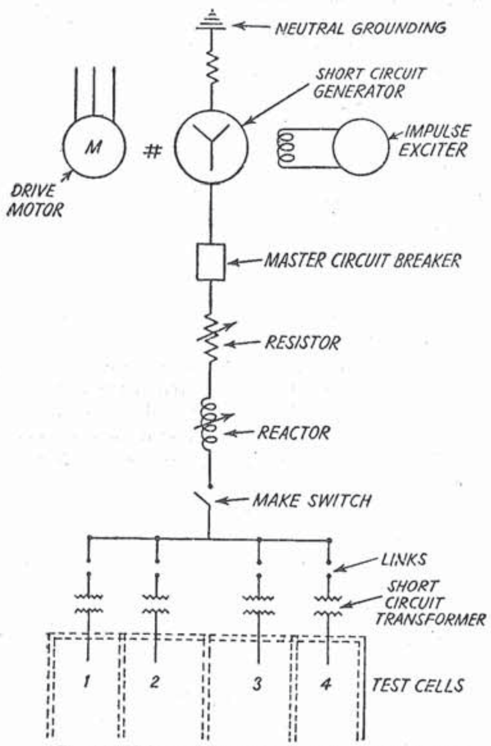
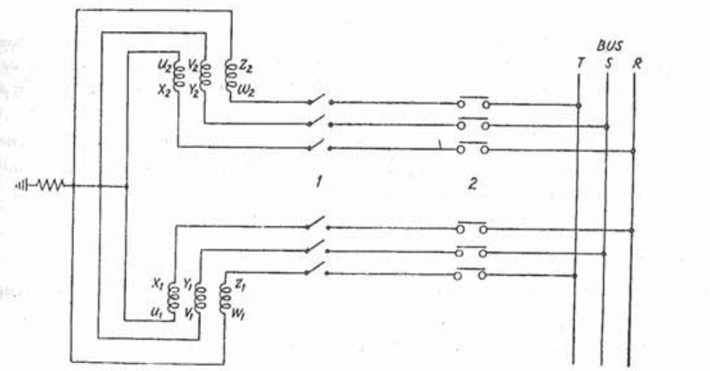


Fig. 11.1. Schematic diagram of short-circuit test plant.

duration. Therefore, their design is different from that of the conventional alternators for power generation.

The generator is driven by a three phase induction motor connected through a resilient shaft. Shortly before the short-circuit, the motor is disconnect from the supply and idles with the generator rotor.

A separate d.c. converter set with a high speak output provides the "Impulse Excitation". The short circuit current which are at lagging power factor have a demagnetising effect. This results in reduction in total field hence in reduced e.m.f. As a results the recovery voltage is less than the voltage before short circuit. The effect is reduced by boosting the generator field current by means of Impulse Excitation. The converter set used for excitation is fitted with a large flywheel. The motor is disconnected from supply before the application of excitation. The field current is increased shortly to about 10 times its normal value at the time of short circuit. This takes care of the demagnetising effect of short-circuit and gives desired recovery voltage.



$\left.\begin{matrix} X_1\,Y\,Z_1 \\ U_1\,V_1\,W_1 \end{matrix}\right\}$	Part 1 of generator winding	1-Making circuit breaker
$\left.\begin{matrix} X_2\,Y_2\,Z_2 \\ U_2\,V_2\,W_2 \end{matrix}\right\}$	Part 2 of generator winding	2-Making switch.

Fig. 11.2. Arrangement of circuit it a short-circuit plant.

Short-circuit generator is a 3-phase alternator. Each winding is made in two or more parts which can be connected in series, parallel combinations of star or delta to get voltages.

(c) **Short-circuit Transformers**

For tests at voltages other than the generator voltage, transformers are used. To step down the voltage to lower values a three-phase transformer is normally used. For voltage higher than generator voltage, usually banks of single phase transformers are employee. These transformers are designed to withstand repeated short-circuit and their windings have several parts which can be connected to series parallel combinations to get several voltages.

The leakage reactance of the short-circuit transformer is kept low. Transformer winding is mechanically strong and provided with extra-turn insulation. Three phase units are not used because a single 3-phase unit becomes too big. There is no special problem about cooling these transformers because they are in the circuit for a short time. The tank is normally smooth without any tubes for circulating oil. For 3-phase tests, the transformers are connected in delta on alternator side. The four windings of each phase on secondary side can be connected in series/parallel combinations and the three phases can be connected in star or delta.

Another three-phase transformer is used for testing low voltage breaker, H.R.C. fuses and for conducting short-time current tests on circuit-breakers.

(*d*) **Reactors**

For controlling the short-circuit current reactors are employed. These are normally air cored and air-cooled. Iron parts are avoided in their construction. These are single phase units or three phase banks. Each reactor is designed to withstand electrodynamic stresses. The coils are securedly placed to avoid distortion.

(*e*) **Master Circuit-breaker**

These are air blast circuit-breakers of capacity more than the breakers under test. In case of failure of the test circuit-breakers, the master circuit-breaker opens. In addition after every test, it isolates the specimen under test from the supply source and must be able to handle the full short-circuit power of the test circuit.

(*f*) **Making Device**

The making switch or making device, as the name implies, is used to ensure that the short-circuit current are applied correctly at the desired moment. This equipment is characterized by close making time, high making capacity. However, the breaking capacity is negligible and the making device is not used for circuit interruption.

The basic construction of making device is as follows. It is usually air blast making switch with an air pressure of 14-16 kgf/cm^2. Contact clearance of only a few mm is sufficient because the contact device is fast, sure and without chapter. In recent stations SF_6 make switches are used.

(*g*) **Capacitor**

Capacitor banks are useful for two purposes :

(1) Provide leading current for testing the performance of circuit-breaker in interruption of charging currents.

(2) Regulating the frequency of transient recovery voltage given by

$$f_n = \frac{1}{2\pi\sqrt{LC}}$$

In synthetic testing and other indirect tests, capacitors are important items in the test circuit.

The capacitor banks provide charging currents, regulate natural frequency of transient recovery voltage and are used for synthetic testing. These are single phase banks. These banks can be connected in series or parallel, as desired, both individually and in any combination of the three.

(*h*) **Resistors**

The variation of short-circuit power factor is obtained by using resistors in series with the reactors. The p.f. can be increased from 0.1 to 0.3.

(*i*) **Test Cubicles.**

The test cubicles are constructions of reinforced cement concrete or strong brick work. In these cubicles the breakers are tested. There is provision for observation. Supply of compressed air and oil purification system is given to the test cells to facilitate testing of air blast circuit-breaker and oil circuit-breakers respectively. Separate cubicles are provided for testing L.V., H.V., E.H.V. equipment, fuses.

(*j*) **Sequence Switch**

During the short-circuit testing several operations are performed in a sequence and the total time is too short to perform manual operation. The sequential switching of equipment measurements and control circuits is accomplished by sequence switch. This is a drum switch with several pairs of contacts. The drum is rotated by a motor. Once the drum is rotated, it closes and opens several control circuits according to a certain sequence. For example, the sequences for Breaking Capacity Test in one test were as follows :

1. Drive motor of short-circuit generator made off.
2. Impulse excitation switched on.
3. Master circuit-breaker closed.
4. Oscillograph circuit connected.
5. Make-switch closed.
6. Circuit-breaker under test opened.
7. Master circuit-breaker opened.
8. Exciter switched off and its field suppressed.

The above operations take a very short time of the order of 0.2 second.

(*k*) **Measurements**

The test events mentioned above cover a very short time of the order of a few hundredth of a second. All the measurements must, therefore, be recorded by means of oscillographs.

Light beam oscillograph which are simple to operate are used for relatively slow varying quantities like current, voltage and also for mechanical quantities such as contact travel, trip signal etc. High frequency transient phenomenon of TRV covers a very short time interval of the order of 1 msec. For recording such fast varying quantities cathode ray oscilloscope are used. Processes which last a few half waves are recorded on barrel type camera. If time is too short, around current zero, Polaroid Oscilloscope camera is convenient. Normally one light beam oscillograph and several cathode ray oscillographs are simultaneously used. High speed photography techniques are being employed for investigating arc extinction phenomenon, movement of part etc. Films are taken at 400 to 800 frames per second.

The following quantities can be recorded during the tests :

(*a*) Short-Circuit current in each phase.

(*b*) Voltage across each pole before, during and after the short-circuit.

(*c*) Fluid (Air, SF_6 or oil) pressure.

(*d*) Contact travel-speed.

(*e*) Generator voltage.

(*f*) Transient Recovery voltage.

(*g*) Current in trip circuit etc.

PART B. DIRECT TESTING

11.4. DIRECT TESTING

Direct testing involves subjecting a complete breaker or breaker pole to full power or stress during the test.

The circuit for direct test is shown in Fig. 11.3.

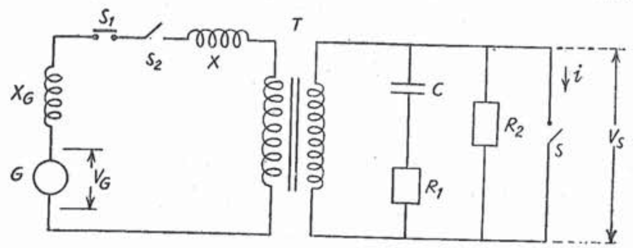
The preliminary preparation of circuit-breaker testing include connecting the equipment adjusting the magnitude of reactors, connecting transformers to get desired test voltages etc. The contacts on sequence switch are adjusted to get desired timings. The oscillographs are adjusted and calibrated. The operations of test follow automatically by means of sequence switch, as mentioned earlier.

While testing breaking capacity; Master circuit-breaker and circuit-breaker under test are closed firts. Short circuit is applied by closing the making switch. The breaker under test is opened at moment. The breaking current determined from the oscillograph as explained in Chapter 3, Sec. 3.19.5.

Making capacity test is necessary type test. All circuit-breakers are tested for their ability to make on to a short-circuit. The master circuit-breaker and the make switch are closed first. The breaker under test is closed on a three phase short-circuit. The making current is determined as explained in chapter 3. Operating duty test are performed according to the Standard Specifications or client's instructions.

11.5. RULES FOR TYPE TESTS

(*i*) **Breaking Current.** The short-circuit current broken by the circuit breaker should be measured at the instant of contact separation as described in chapter 3 and should be stated in terms of two values : Breaking current and d.c. component (Ref. Sec. 3.19.5.)



V_G = Generator voltage
i = Short circuit current
X = Current control reactance
S_2 = Making Switch
S = Breaker under test.
G_S = Voltage across test breaker
X_s = Generator reactance
S_1 = Back-up (Master) circuit-breaker
T = Transformer
C, R_1, R_2 = Capacitance, resistance for adjusting the transient recovery voltage
G = Short circuit generator.

Fig. 11.3. Short-circuit test arrangement (single line representation).

(*ii*) **Breaking Capacity.** The breaking capacity test should be performed with specified TRV of test circuit.

(*iii*) **Peak Making Current.** The peak making current made by the circuit-breaker during the test should be expressed by maximum current in any pole. It is measured as described in chapter 3, Sec. 3.19.6.

(*iv*) Conditions of severity for Making Capacity and Breaking capacity tests are specified as under the following clauses :

1. Conditions of breaker before test.
2. Conditions during the test.
3. Conditions of breaker after test.
4. Applied voltage before test.
5. Transient recovery voltage.
6. Short-circuit power factor.
7. Test frequency.
8. Earthing of test circuit.
9. Test duties.

11.6. SHORT-TIME CURRENT TESTS ON CIRCUIT-BREAKERS, ISOLATORS, BUSBARS, CTs ETC.

(*a*) **Requirement.** Short time current tests are Type Tests for confirming Rated Duration of Short-circuit current (1 sec or 3 sec) assigned by the manufacturer (Ref. Sec. 3.19.7).

Rated short time current is defined as the r.m.s. value of a.c. current which the circuit-breaker can carry for a specified short duration (1 sec or 3 sec) without mechanical damage and without contact welding.

Short-time current tests are necessary type tests for circuit-breakers, bus bars, metal-clad switchgear, current transformers, bushings, isolators etc. The procedure described here is applicable in all cases.

(*b*) **Test voltage.** Short-time current tests may be carried out at any suitable test voltage. The voltage is selected by testing station authorities depending upon the reactance of the equipment and required value of short-time current.

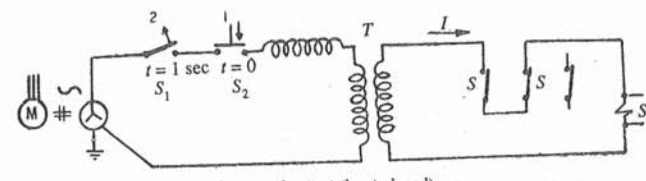
(*c*) **Single-phase Tests or Three-Phase Tests.** Both single phase tests and three phase tests are permitted by the standard. However a complete triple pole breaker is installed in the test bay for the purpose of tests. The single phase tests are carried out by connecting two adjacent poles in series.

In case only single pole is to be tested, a rigid return conductor is installed at the centre-line of adjacent pole to simulate the electrodynamic forces between adjacent poles. For circuit-breakers above 72.5 kV the return conductor is not necessary because of the large clearance and reduced electrodynamic forces.

(*d*) **Test Circuit** (Ref. Fig. 11.4 *a*, *b*). The circuit-breaker is connected on the low-voltage side of short-circuit transformer for testing station. The short-circuit is applied beyond the circuit-breaker *via* a shunt of measurement.

In single-phase test, the two adjacent poles are connected in series. The short-circuit current is passed through the closed series circuit and the shunt.

In three-phase test, the three terminals of the circuit breaker on one side are connected to low-voltage side to short-circuit transformer of testing station. The other three terminals of poles are connected in star *via* shunt in each phase for measurement of current.



S, S = Adjacent poles of circuit-breakers under test (kept closed)
S_1 = master circuit-breaker opened at $t = 1$ sec
S_2 = Make switch, open before $t = 0$, closed at $t = 0$
I = Rated short-time current
T = Low secondary voltage transformer
Sh = Shunt for measurement of current I

Fig. 11.4. (*a*) Explaining single-phase short time current test on a circuit-breaker or isolator.

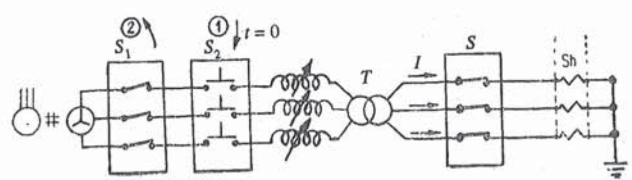


Fig. 11.4. (*b*) Three phase Test circuit.

(*e*) **Procedure.** The magnitude of short-circuit current is achieved by selecting appropriate voltage and reactance by the testing authorities depending upon the reactance of the circuit-breaker under test and the required value of current. Trial shots are taken at reduced voltage and current to check the calibration.

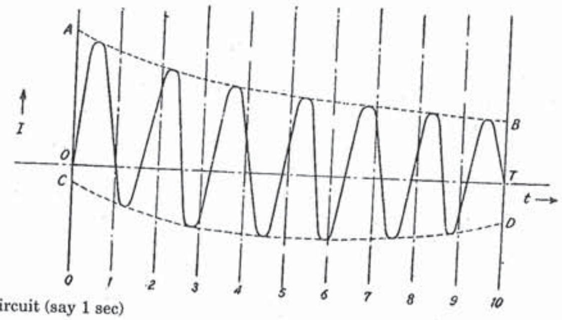
For this test, the circuit-breaker under test (S) is kept in closed condition throughout the test.

Short circuit current is initiated by closing the station make switch (S_2) at $t = 0$ sec and current is interrupted opening master circuit breaker (S_1) at $t = 1$ sec or 3 sec. The peak of first major current loop should be 2.5 times rated short time current (Ref. Sec. 3.19.6).

The record is obtained on the oscillograph on the sheets of ultraviolet recorder automatically.

(*f*) **Observations.** Visual inspection and no-load operation of the circuit-breaker immediately after the short-time current test are usually sufficient. The parts of the circuit-breaker should not get damaged during the test. The circuit-breaker should not emit any flame or smoke. The contacts should not get welded. The circuit-breaker should be capable of opening and closing after the short-time current test.

(*g*) **Short-Time Current Test, Evaluation of Test Results.** Fig. 11.5 shows an example of oscillogram taken during the short-time current test. The current is passed the breaker for a short-time (1 sec) and the oscillogram is taken.



0T duration of short-circuit (say 1 sec)

$\left.\begin{array}{l} AB \\ CD \end{array}\right]$ Envelope of short-circuit wave

$I_0, I_1, I_2, \ldots\ldots I_{10}$ r.m.s. value of asymmetrical current at each instant.

Fig. 11.5. Oscillogram of short-circuit of short time current test.

The r.m.s. value of current during the time interval 0 to T of such a wave is given by the expression.

$$I_{rms} = \sqrt{\frac{1}{T}\int_0^T i^2\, dt}$$

where i is the current (variable)

t time (variable) (seconds)

T duration of current in seconds.

Procedure of determining equivalent r.m.s. value of short-time current is as follows. The time interval $0T$ is divided into 10 equal parts marked by 0, 1, 2,....etc. upto 10. The r.m.s. values at these instants are I_0, I_1, I_2.....etc. upto I_{10}

$$I_{rms} \text{ at this instant} = \sqrt{(I_{sym})^2 + (I_{d.c.})^2}$$

where I_{sym} = r.m.s. value of a.c. component at this instant

$I_{d.c.}$ = component at this instant.

It is r.m.s. value of current at this instant. This way I_0, I_1, I_2......etc. upto I_{10} are calculated. From these values the r.m.s. value of short time current is calculated with sufficient accuracy by *Simson Formula :*

$$I = \sqrt{\frac{1}{30}\left[I_0^2 + 4\left(I_1^2 + I_3^2 + I_5^2 + I_7^2 + I_9^2\right) + 2\left(I_2^2 + I_4^2 + I_6^2 + I_8^2 + I_{10}^2\right)\right]}$$

Temperature rise limits are not specified for short-time current tests. It is very difficult to record the transient temperature during 1 sec. duration.

(*h*) **Stresses during Short-time Current Test.** The electrodynamic forces between adjacent poles and adjacent phase conductors are proportional to square of current and inversely proportional to phase spacing. During short-time current, the insulator supports experience impact cantilever force due to electrodynamic forces.

The contacts experience temperature stresses proportional to I^2 Rt. The resistance depends on contact pressure and surface condition.

11.7. BASIC SHORT-CIRCUIT TEST DUTIES (Ref. Sec. 10.27.3.15)

(*a*) **Requirements.** *The circuit-breaker should be capable of performing the opening and closing operations as per rated operating sequence for all values of short-circuit currents upto its rated short-circuit breaking current at specified test voltage and relevant conidtions of TRV for terminal short-circuits.*

The requirements are verified by conducting Basic short circuit. Test Duties. These requirements are discussed below :

(*i*) **Breaking Capacity** (Ref. Sec. 3.19.5. (Ref. Fig. 11.12)

The Circuit-breaker should have rated short-circuit current breaking capacity. It should be capable of breaking all currents upto its rated short-circuit breaking currents. Since it is difficult to carry out tests at every value, the basic short-circuit tests are made at 10%, 30%, 60% and 100% of rated short-circuit breaking current (a.c. component) and specified d.c. component.

(*ii*) **TRV Conditions**

The circuit-breaker should have rated TRV for terminal faults (Ref. Sec. 3.19). During Breaker operations, the TRV should be as per specified TRV condition for the respective test duty.

TRV for test Duty 1 (10%) and Test Duty 2 (30%) are more severe than those for Test Duty 3 (60%) and Test Duty 4 (100%)

(*iii*) **Making Capacity.** (Ref. Sec. 3.19.6.) (Ref. Fig. 11.12)

The circuit-breaker should be able to close on short-circuit, *i.e.*, it should have rated short-circuit making capacity. This is tested by closing the circuit-breaker on short-circuit.

(*iv*) **Operating Sequence.** (Ref. Sec. 3.19.8) (Fig 12.11)

The circuit-breaker should be able to perform the opening and closing duties as per rated operating sequence. The requirement is verified by conducting the Basic Short-Circuit Test Duties with rated operating sequence.

(*b*) **Procedure.** For breaking capacity tests (TD 1, TD 2, TD 3 and TD 5), the short-circuit currents are initiated by closing the make switch of the testing station and the current is interrupted by opening the circuit-breaker under test. The circuit-breaker under test is not closed on short-circuit (Ref. Fig. 11.12)

For making capacity tests (TD 4a) the short-circuit is initiated by closing the circuit-breaker under test. The opening of short circuit current is by master-breaker of the testing station. The circuit-breaker under test need not to open the short-circuit.

The sequence of circuit-breaker under test, master circuit-breaker and make switch is pre-arranged to get desired duty cycle.

(*c*) Test circuit (Ref. Fig. 11.3) The basic short-circuit tests are carried by out on complete three pole circuit-breaker. However, when capacity of the testing station is inadequate for testing a complete three phase circuit-breaker the test may be carried out on one pole of a three phase circuit-breaker. Even then, a complete circuit-breaker is usually installed in the test bay and only one pole is connected in the circuit. In case of EHV circuit-breakers with modular construction, the tests may be carried out on pole. The test voltage is selected such that rated power frequency recovery voltage is obtained. The test voltage is selected such that rated power frequency recovery voltage is obtained.

The parameters L and C in the station are arranged such that the required current and TRV conditions are achieved L and C are changed for each test duty.

(*d*) **Severity.** Basic short-circuit test duty produces severe electromechanical, thermal and dielectric stress on circuit-breaker. The severity of these components varies with Test Duty 1, 2, 3, 4*a*/4*b* and 5 depending upon type of circuit-breaker. For circuit-breakers with internal source of energy, the smaller breaking currents generate less pressure. Hence TD 1 and 2 may be more severe. When arcing time for Test Duty 1 and 2 is more by 1/2 cycle than Test Duty 3 and 4, the Critical Current Tests are necessary.

11.8. CRITICAL CURRENT TESTS (Ref. Sec. 8.7)

In circuit-breaker with internal source of extinguishing energy *i.e.*, oil circuit-breakers, the arc duration depends upon design of cross-jet pot and speed of contacts. The arcing time for Test Duty 1 (10%) may exceed that of Test Duty 2 by more than one-half cycle. In such cases, additional 'Critical Current Tests' are required.

Critical current test duties are similar to Test Duty 1 except for following changes.

— The breaking currents are in the range of 4 to 6% and 1 to 2% of rated short-circuit breaking current.

— TRV conditions are modified.

11.9. SHORT-LINE FAULT TESTS (Ref. Sec. 3.14.1)

(*a*) **Requirements.** These tests are applicable to three pole circuit-breakers intended for direct connection to overhead transmission lines having rated voltage of 72.5 kV and above.

These are not applicable to 36 kV and 12 kV circuit-breakers. The theory of short-line faults has been discussed in Sec. 3.16. The capability of the circuit-breakers to perform the short-line fault clearing duty is tested by conducting these tests. In high power testing station, the transmission line is generally represented by an artificial transmission line comprising R, L, C parameters or by specially built transmission line.

For purpose of short line fault simulation, the system can be considered in two sides (Ref. Sec. 3.16)

— Source side having rated voltage and equivalent inductance corresponding to 10% rated short-circuit breaking current.

— Line side impedance.

To represent different lengths of lines and corresponding short-line fault current, these values of line side impedances are recommended. These are selected to get 90%, 75% and 60% of rated short-circuit breaking current respectively.

(*b*) **Test Circuit.**. The short line fault tests are single phase tests. The circuit consists of a supply circuit and line side circuit. The parameters are so selected that required TRV conditions are obtained.

(*c*) **Short line Fault Test Duties.** The standard test duties L90, L75, L60 consist of rated operating sequence for opening operation only as follows :

Test Duty L90 : At 90% rated breaking current and appropriate TRV.

Test Duty L75 : At 75% rated breaking current and appropriate TRV.

Test Duty L60 : At 60% rated breaking current and appropriate TRV.

(*d*) **Severity.** After opening a short-line fault, voltage waves originating in the circuit-breaker travel to source side and line side. The line wave gest reflected from the fault point and thus within a few tens of microsecond, the wave travels to-and-fro between the open circuit breaker and the

fault point giving rise to damped saw-tooth oscillations of voltage at line side terminal of circuit-breaker. The result and TRV across the circuit breaker is characterised by high rate of during initial portion of TRV (Ref. Sec. 3.16). Different types of circuit-breakers have different sensitivity of TRV. The grading capacitors dampen the TRV.

Value $V_p = V\sqrt{3}$

I_L = Short line fault current.

C_B = Circuit-breaker under test.

X_L = Reactance on line side.

X_S = Reactance on source side.

Z = Surge impedance of line.

L = Length of line upto fault.

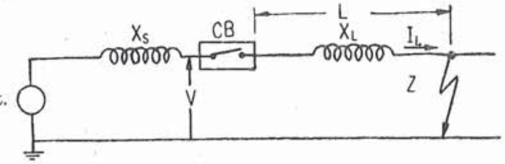


Fig. 11.6. Circuit representing Short Line Fault condition.

11.10. LINE CHARGING BREAKING CURRENT TESTS

(*a*) **Rated line charging breaking current.** It is the value of line charging current taken by the line no load. The circuit-breaker is capable of interrupting with over-voltage within permissible limits. Breaker should not restrike.

Rated Voltage (V)	*Rated line charging current*
KV	*A*
72.5	10
145	50
245	125
420	400
525	500

(*b*) **Requirement.** These test are conducted of h.v.a.c. circuit-breakers rated 72.5 kV and above to prove their assigned rated line charging breaking current.

(*c*) **Test Circuit.** The tests are either single phase or three phase with either overhead line on on-load or with artifical line with R, L, C.

The supply circuit has two types :

Supply Circuit 1 : Which can give short-circuit current less than 10%.

Supply Circuit 2 : Which can give short-circuit current more than rated short-circuit current.

(*d*) **Test voltage.** In single phase tests, the test voltage V_t is given by

$$V_t = 1.2 \times \frac{V}{\sqrt{3}}$$

where V is rated voltage of circuit-breaker.

(*e*) **Test Duties.** Test 3 is applicable only if the circuit-breaker restrikes during test duty 1 or 2. The test consists of 10 to 12 operations for each duty.

Test Duty No.	*Supply Circuit*	*Test current as percentage of rated line charging current*
1	1	10 to 30
2	1	100 to 120
3	2	100 to 110

11.11. OUT-OF-PHASE SWITCHING TESTS

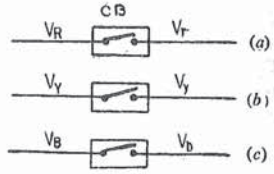


Fig. 11.7.

(a) **Requirements.** When a circuit-breaker is connected between two circuit supplied from different sources, the circuit-breaker may have to open or close during out-of-phase condition [Fig. 11.7 (a) or phase opposition [Fig. 11.7 (b)]. The phase angle between rotating vectors on either sides of the circuit-breaker may exceed normal value (0°) and may be as much as 180° (Phase opposition). The circuit-breakers which are required to inter-connect two systems or to synchronise the units with the busbars need rated out-of-phase breaking capacity. The circuit-breaker should be capable of breaking out-of-phase currents upto its assigned ratings with specified conditions of TRV. (Ref. Sec. 3.17)

(b) **Test Conditions.** The out-of-phase breaking are either single phase or three phase. The performance out-of-phase breaking capacity in a test is specified in terms of the following :

— Value of out-of-phase breaking current

— Value of out of phase recovery voltage

— Characteristics of inherent TRV for out-of-phase switching.

Test Voltages

For single phase test, the test voltage (V_1) given by the following expressions :

$V_t = 2 \times \frac{V}{\sqrt{3}}$ For effectively earthed system.

$V_t = 2.5 \times \frac{V}{\sqrt{3}}$ For non-effectively earth system.

Where V is rated voltage of Circuit-breaker.

(a) **Out-of-phase Test Duties**

Test Duty 1 : 0 and 0 at 20 to 40% I_{op}

Test Duty 2 : 0 and 0 at 100 to 110% I_{op}

where I_{op} is rated out-of-phase breaking current, O is opening.

The rated out of phase breaking current is generally 25% of rated breaking current of circuit-breaker.

11.12. CAPACITIVE CURRENT SWITCHING TESTS

Capacitor current switching is a special switching duty for a circuit breaker (Ref. Sec. 3.14, Sec. 3.19.19). Capacitor current switching tests are applicable for circuit-breakers which are intended to be used for breaking capacitive currents. The breakers should be restrike free. The switching overvoltages while opening single capacitor banks should be within permissible limits.

Circuit breakers to be used for closing parallel capacitor banks should be tested for rated back-to-back capacitor bank breaking current and rated capacitor bank inrush making current. Ref Sec. 15.26 for capacitor switching applications for medium voltages.

Applicability

Capacitive current switching tests are applicable to all circuit-breakers to which one or more of the following ratings have been assigned.

— Rated line-charging breaking current (Sec. 11.10)

Line charging current switching tests are recommended circuit-breakers for rated voltages of 72.5 kV and above.

— Rated cable-charging breaking current (Sec. 11.13)

Cable-charging current switching tests are recommended for circuit-breakers of rated voltages of 24 kV and above to be used of switching cable currents.

— Rated single-capacitor bank breaking current.

Rated single capacitor bank current breaking tests are recommended for circuit-breaker to be used for switching capacitor banks. The breaker should be restrike free and switching overvoltages should be within specified limits.

— Rated back-to-back capacitor bank breaking current and

— Rated capacitor bank inrush making current.

These tests are intended for circuit-breakers which switch in or switch out *parallel capacitor banks.*

Supply Circuit A

Supply circuit A is a circuit having an impedance such that its short-circuit current does not exceed 10% of the rated short-circuit current of the circuit-breaker except that, if necessary, the impedance shall be reduced below the value given by this requirement so that power frequency voltage variation caused by switching the capacitive current does not exceed 10%.

Supply Circuit B

Supply circuit B is a circuit having impedance which is as low as possible, but not so low that its short-circuit current exceeds the rated short-circuit current of the circuit-breaker. The characteristics of the test circuit shall be such that the power frequency voltage variation when switching is as small as possible and is in any case less than 5% for Test-duty No. 4.

Test duties

Test conditions corresponding to normal service conditions.

The capacitive current switching tests shall consist of four test-duties as specified in Table below.

Test-duty	*Supply circuit*	*Test current as percentage of the rated capacitive breaking current*
1.	A	20 to 40
2.	A	Not less than 100
3.	B	20 to 40
4.	B	Not less than 100

The number of tests for each test-duty shall be :

—10 tests for three-phase tests :

—12 tests for single-phase tests with the contact separation distributed at intervals of approximately 30 electrical degrees.

Test duties for Capacitive current Switching tests

Test Duty	*1*	*2*	*3*	*4*
Test Circuit	A	A	B	B
Line Current Switching tests and cable charging current switching tests.	O	C, P	P	C, O
Capacitor bank Current switching tests	O	C, O	O	C, O

Last two shots of the test duty to be C, O

C = Close; O = open.

Criterion of Suitability of circuit breaker.

The capacitive current switching tests are performed to prove respective assigned ratings.

The breaker is considered to be suitable for respective capacitive current switching duty (Sec. 11.10.1) if the breaker is restrike free during opening and can withstand inrush currents of specified frequency and peak during closing. The switching overvoltages should be within specified limits.

11.12.1. Single Capacitor Bank Current Breaking Test

(*a*) **Requirement.** These tests are applicable to circuit-breakers which are intended for opening capacitive loads such as Capacitor banks. Capacitor banks are used for power factor improvement (reactive power compensation) at receiving end of transmission lines. The circuit-breakers used for switching such capacitor banks should have the rated capacitor breaking current.

(Ref. Sec. 3.14). These should be restrike free.

(*b*) **Rated Capacitor Breaking Current.** This is a assigned by the manufacturer on the basis of development and proving test. This current varies between a few tens of amperes and a few hundred amperes for circuit-breakers rated 12 kV, 36 kV and 72.5 kV. Alternatively, the capacity is expressed in terms of three phase MVAR given by

$$\text{MVAR} = \sqrt{3} \times \text{kV} \times \text{kA}$$

For example at 36 kV circuit-breaker with rated capacitor breaking current of 600. A will have a breaking capacity equal to

$$\sqrt{3} \times 36 \times \frac{600}{1000} = 37.4 \text{ MVAR}$$

(*c*) **Test Circuit.** The tests can be either single phase tests or three phase tests depending upon available test facilities. (Ref. 11.6). The tests are conducted with two types of supply circuits as follows :

Supply Circuit I. With higher inductance on supply side such that short-circuit current is less than 10% or rated short-circuit current.

Supply Circuit II. With low inductance on supply side such that short-circuit is more than 100% rated short-circuit current.

(*d*) **Test Duties.** The single capacitor breaking test comprises for test duties as mentioned below. For each test duty, 10 shots are taken for three phase tests or 12 to 30 shots for single phase tests.

Test Duty	*Supply Circuit (See clause C)*	*Test current as a percentage of rated capacitor breaking current*
1	1	20 to 40%
2	1	100 to 110%
3	2	20 to 40%
4	2	100 to 110%

The tests sequence in Test Duty 4 are make-break tests.

(*e*) **Severity and Performance Evaluation.** During closing on capacitor banks, the inrush currents have high frequency. The energy released in prearcing causes heating and pressure rise which depends on magnitude and frequency on inrush currents. Each circuit-breaker has a limit of closing duty with regard to frequency and magnitude of current.

During opening operations, the circuit-breaker should not restrike and should not produce over-voltage above permissible limits (Ref. Sec. 3.19, Table 3.4)

11.13. CABLE-CHARGING BREAKING CURRENT TEST

(*a*) **Requirement.** The circuit-breaker for opening high voltage cables or cable networks should be capable of interrupting the charging currents of cables successfully with the over voltage within specified limits. The recommended value of rated cable charging breaking current are as follows :

Rated Voltage	*Rated cable charging breaking current*
kV	*A*
3.6	10
7.6	10
12	25
36	50
72.5	125
145	160
245	250
420	400

(*b*) **Test Conditions.** These tests are either field tests or laboratory tests. Field tests are conducted on actual cable. Laboratory tests are conducted by employing cables or capacitors. Single phase tests are permitted for 36 kV and above.

Test Circuits

Test circuit 1 has such impendance that the S.C. current does not exceed 10% of rated short-circuit current of the breaker. Test circuit 2 has impedance that short-circuit current exceeds rated short circuit current of the circuit-breakers.

(*c*) **Test Duties.** For each of the duty 10 to 12 opening and at least two make-break operations are conducted.

Test Duty	*Supply Circuit*	*Test current as per cent of rated cable changing breaking current*
1	1	20 to 40
2	1	100 to 110
3	2	20 to 100
4	2	100 to 100

11.13.1. Small Inductive Current Breaking Tests

(*a*) **Requirements.** The circuit-breakers to be used in following cases should have assigned value of Rated Small Inductive Breaking Current.

- Steady magnetizing current of power transformers.
- Inrush currents of power transformers.
- Currents of shunt reactors or reactor loaded transformers.
- Currents of small high-voltage motors during starting periods.

The term 'small inductive current' refers to current having power factor less than 0.15 and which are usually lower than the rated normal current of circuit-breakers. In some cases (in-rush current of transformers or motors) the value of small inductive current may be more than the rated current of the circuit breakers.

The circuit-breaker should not produce over-voltage beyond the specified limits during breaking of small inductive currents.

(*b*) **Rated Small Inductive Breaking Current.** The Rated Small Inductive Breaking Current Capacity is the highest value of small inductive current which the circuit-breaker is capable of breaking with over-voltages within specified limits.

The frequencies of TRV are based on duration of first loop of voltage after final current zero. (Ref. Sec. 3.12).

(*c*) **The Test Circuit.** The Test circuit is illustrated in Fig. 11.8. Tests are either single phase or three depending upon the availability of load.

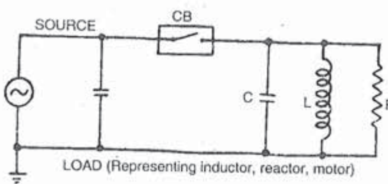


Fig. 11.8. Test Circuit for Small Inductive Current-Breaking.

(*d*) **Test Results.** The circuit-breaker should be capable of opening the circuit with overvoltages with specified limits. In case, overvoltages are beyond the limit, suitable surge suppressors (R-C) combination should be connected on load side and interrupter design may be modified. Switching resistors may be incorporated in the circuit-breaker. (Ref. Sec. 3.13.)

11.13.2. Recommendations for Small Inductive Current Switching Tests

The switching overvoltages produced by small inductive current switching are related with current chopping phenomena. The overvoltage waveform can have different shapes. It is difficult to assess the degree of effect of such wide range of wave shapes on insulations of loads and supply circuits.

Clean shopping overvoltage without reignitions may be compared with standard switching Impulse Wave (SIW) of 250/2500 μs in case of EHV circuit switching.

For medium voltage circuits standard Lighting Impulse voltage wave (LIW) of 1.2/50μs may serve as guideline. Recommendations of IEC 56 1987 for small inductive current switching tests are summarised below :

1. Transformer magnetizing current for circuit-breakers with rated voltages of 100 kV and above.

Experience indicates that when interrupting magnetizing currents of unloaded transformers under steady state conditions and at voltages not exceeding their rated voltage the over-voltages are small. Tests are therefore, not specified to simulate this switching condition.

Switching of the inrush magnetizing current of an unloaded transformer is not a normal service condition and no tests are specified.

2. Transformer magnetizing current for circuit-breakers with rated voltages below 100 kV.

Generally tests are not required but in cases of doubt they should be made on the system under actual service conditions. If this is not possible, three-phase tests may be made in a laboratory using the actual transformer to be switched in service. In either case, the source circuit should have as low a capacitance as possible subject to the rated TRV not being exceeded. Any means of voltage limiting to be used in service may be connected for the tests.

3. Transformer with a teritary winding loaded with reactors.

This shall be considered a special case and agreement reached between manufacturer and user.

4. High voltage motors.

A test circuit is under consideration of IEC (1988)

5. Shunt reactors.

A test circuit is under consideration if IEC (1988)

11.14. REACTOR SWITCHING TEST

The laboratory tests do not give true representation of actual network conditions. However, laboratory test has been proposed by CIGRE (1987) and is likely to be recommended in the next revision of IEC 56.

(*a*) **Test Duties**

CIGRE 1987 recommends the following test circuit for Medium Voltage and High Voltage Reactor switching.

Rated voltage of CB kV	*Test duty*	*Current**	*Natural frequency of Load** kHz.*	*Natural frequency of Loop Hz*
12-36	A	500	9-11	150—200
	B	1500	18—22	150—200
	A	2300	1.8—2.2	150—200
36-72.5	B	500	3.6—4.4	150—200
	A	100	0.9—1.1	150—200
72.5 and above	B	300	1.6—1.8	150—200

(*b*) **Purpose of Test.**

Reactor current breaking tests are performed with following purposes :

A1. To prove the interrupting ability of the CB or the switch to interrupt the reactor currents.

A2. To confirm that reignitions occurring during reignition are not harmful.

A3. Investigations of the breakers behaviour mainly in respect of overvoltages production with following respects.

— to determine maximum chopping current.
— to investigate statistical distribution of the chopping current.
— to investigate statistical distribution of the chopping current.
— to investigate reignition probability, to determine the range of point-of-wave settings with reignitions.
— to estimate the dielectric characteristic of contact gap.

Conclusions.

Interruptions of reactor currents may create overvoltage of the two types :

— Chopping overvoltages having high magnitudes of time duration approximately corresponding to switching impulses.
— Reignition overvoltages overvoltage having time duration similar to lightning impulses but lower crest values.

Expected over voltages.

Chopping overvoltages : below 2 p.u.

Reignition overvoltages : 2 p.u.

For circuit-breakers of rated voltages above 275 kV overvoltages above 2 p.u. may not be permitted.

Method to Limit Overvoltages during Reactor Switching.

— Use of opening resistors with current breakers

* Current of p.f. less than 0.15.

** For first pole-to-clear, the worst overvoltages occur due to current chopping at lower values of currents. Hence test duties A performed with lower value of current.

— Use of ZnO arresters near the circuit-breaker

— Use of high capacitance between breaker and reactor connected between phase to earth.

Means to Limit switching overvoltages during opening of small inductive currents and reactor currents include the following.

1. *Use of opening Resistors* (Resistor Switching)

To reduce the overvoltage amplitudes, two different ranges of opening resistors are used.

— Resistance values of the order 10 to 50 Kilo-ohms per phase.

— Resistance values of the order 1 to 5 Kilo-Ohms per phase.

The resistances used for damping TRV of short circuit currents interruption are several hundred ohms (for line CB) down to a few ohms for generator CB.

Resistance current is interrupted by auxiliary break.

2. *Use of ZnO Arresters in parallel with the circuit-breakers.*

This is an alternative to the use of opening resistors to reduce peak-to-peak excursion of overvoltage due to reignition.

The protective level of the ZnO arrester may be kept between 1.5 p.u. and 2.0 p.u. However additional surge arresters are essential for phase to ground between the CB and the reactor.

3. *Capacitor between breaker and reactor.*

This reduces steepness and amplitude of overvoltage. However it complicates the generation and limitation of overvoltage.

Special Note

Laboratory tests for reactor switching and low inductive current switching are for obtaining information about the influence of the CB on the overvoltages. For determination of overvoltages in actual installation, field testing is recommeded by CIGRE.

PART C—INDIRECT TESTING

The short-circuit power available in earlier testing stations (of the order of 4000 MVA in laboratory type testing station) is not sufficient to test a complete breaker (which is of rated breaking capacity of the order of 10,000 MVA at 245 kV). Even single pole of a EHV circuit-breaker cannot be tested by direct means. As all EHV circuit-breaker are with several arc interrupter units tested per pole each unit can be separately tested. This is called Unit Testing. From tests on one unit, the capacity of the complete pole and breaker is determined. This method of Unit Testing is adopted internationally. Synthetic testing is another popular method which permits testing of breaker of capacity 5, times that of the plant.

The important indirect Methods include the following :

1. *Unit Testing**. Which means testing one or more units separately.

2. *Synthetic Testing**. In which the current source providing short circuit current and voltage source supplying restriking and recovery voltage are different.

3. *Substitution Tests.* These are conducted for oil circuit-breaker, the characteristics of current versus time are obtained for different voltages. The performance beyond the tested values is determined by approximation.

4. *Compensation Tests.* Which are conducted on oil circuit-breakers in critical range of low current by a suitable compensation such as increased frequency, increase restriking voltages etc.

5. *Capacitance Tests.* The capacitor which is charged by a voltage source is discharged through the breaker. An oscillatory circuit provides restriking voltage.

* Most widely used indirect test used for Type Testing.

11.15. UNIT TESTING OR ELEMENT TESTING

Almost all modern EHV circuit-breakers, minimum oil, Air Blast, SF_6 etc. consist of two or more identical units (or interrupters) per pole. These interrupters operate (open or close) simultaneously and share the voltage across the pole almost equally. The breaking capacity in M.V.A. is also shared equally. Hence by testing one unit, the results can be applied to the capacity of the pole. This is known as Unit Testing or Element Testing. Element testing in an internationally accepted method.*

While applying unit test the voltage must be reduced by factor a and all the impedances should be reduced by factor a to get test voltage across the unit same at that following expressions :

$a = \frac{1}{n}$ when one unit is rested together.

$a = \frac{m}{n}$ when m units are tested together.

where n is number of units per pole.

For example consider 3 pole, 230 kV circuit-breaker with three units per pole. Test is to be conducted at normal voltage *i.e.* 230 kV between poles. Voltage across one pole is $230/\sqrt{3} = 133$ kV.

$$a = \frac{1}{n}, \; n = 3$$

∴ Voltages required for testing one unit

$$= a \times 133 = \frac{1}{3} \times 133 = 44.33 \text{ kV}$$

Further : L and C of test circuit should be reduced to get same natural frequency as that direct testing, *i.e.*

$$f_n = \frac{1}{2\pi\sqrt{LC}} \text{ in Direct Testing}$$

$$f_n = \frac{1}{2\pi\sqrt{aL \times \frac{C}{a}}} = \frac{1}{2\pi\sqrt{LC}}$$

The natural frequency of transient restriking voltage remains unchanged. Time scale also remains unchanged.

With breakers in which the voltage distribution across the pole is not evenly distributed amongest the units, some units will be stressed more and the others less. The test should be performed so as to test the highest stress coming over the unit. Hence correction must be made in unit testing results. Statistically, unit testing has been established as a reliable method of testing.

11.16. SYNTHETIC TESTING

Fig. 11.9 illustrates the principle of synthetic testing.

The synthetic test employs two sources namely.

(1) Current source (of relatively low voltage)

(2) Voltage source (of relatively low current).

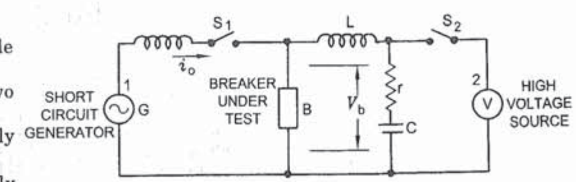


Fig. 11.9. Synthetic Testing Test Circuit (simplified).

* If two interrupters are coupled in series, the double-interrupter assembly should be tested together as a 'unit'. (Ref. Sec. 11.7 C).

If testing station has a capacity, complete breaker is tested instead of unit testing.

The current source provides short-circuit current. The voltage source provides restriking voltage plus recovery voltage. Other L, r, C etc. are used to get desired test conditions. The switch S_1 is closed to supply short-circuit current L_G. At near final current zero switch S_2 (which is usually a spark gap) is closed and V_3 is applied to the breaker at an appropriate moment. The voltage will have transient because of L and C of the circuit.

The advantages of this method are the following.

(1) The breaker can be tested for desired TRV and R.R.R.V.

(2) The short-circuit generator has to supply currents at a relatively less voltage (as compared to direct testing).

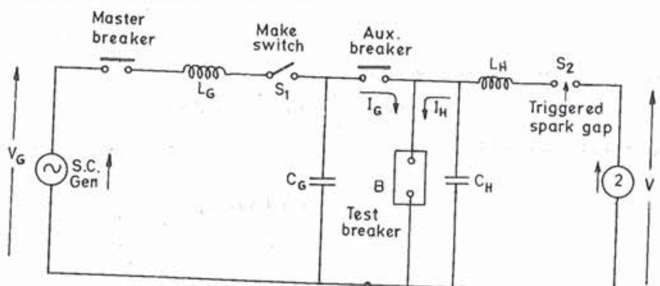
(3) Both test current and test voltage can be independently varied. This gives flexibility to the test.

(4) The method is simple. It can be applied to unit testing also.

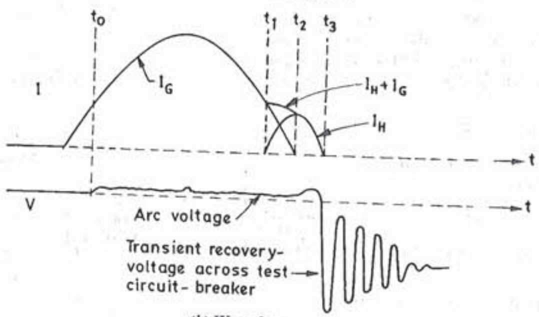
(5) With this method a breaker of capacity (MVA) of five time that of the capacity (MVA) of the test plan can be tested.

Types of Synthetic Test Circuits

There are two types of synthetic test circuit.



(a) Parallel current injection



(b) Waveforms

Fig. 11.10. Synthetic Test Circuit and waveform based on Parallel Current Injection Method.

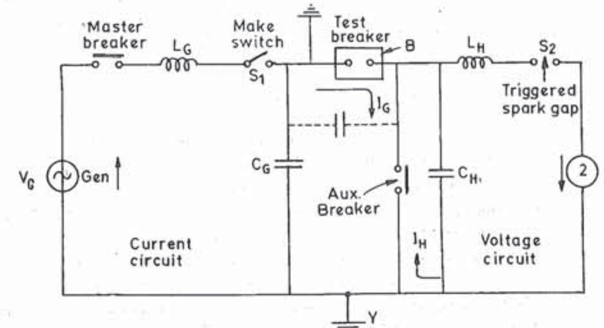
[In parallel current injection method, voltage circuit (2) is effectively connected in parallel with current (1) and the test breaker 'B' before the main current I_G reaches zero. This method is widely used for synthetic test circuits for getting frequencies of TRV]

— Parallel Current Injection Method (Fig. 11.10)

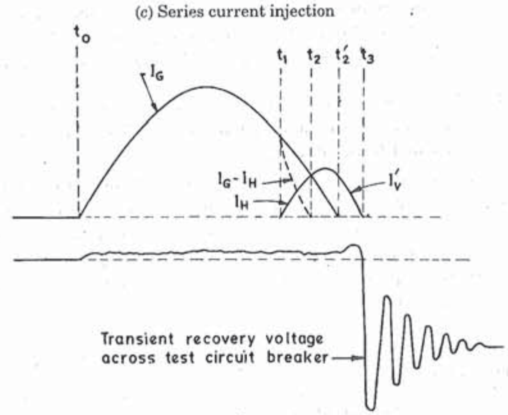
— Series Current Injection Method

Parallel Current Injection Method widely used for testing circuit-breakers because it can give high frequency transient voltages as required by standards.

Ref. 11.10 (*a*). In parallel current injection method, the voltage circuit (2) is effectively connected *in parallel* with current circuit (1) and the test breaker *before* the main current I_G in test breaker current is properly simulated.



(c) Series current injection



(*d*)

Fig. 11.10. Synthetic Test Circuit and waveform based on Series Current Injection Method.

Fig. 11.10 (*c*) represents series current injection method, in which the voltage circuit (2) is connected to current circuit in series before main current zero. As a result the I_H and I_G are in opposition in breaker circuit.

Stresses produced by synthetic test should correspond to those in actual network. This is difficult. Several factors influence the stresses during the test. These include.

— High current mode

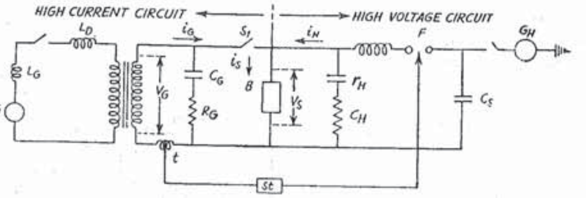
— instant of applying voltage

— frequencies of TRV etc.

— High voltage mode

— t_1, t_2, t_3, t_2 (Ref. Fig. 11.10)

Brown Boveri's Synthetic Testing Circuit. Synthetic test circuit shown in Fig. 11.11 is used by Brown Boveri, Switzerland. It is used in such a fashion that the short-circuit current is supplied from a circuit at a relatively low motive voltage while the restriking and recovery voltage is supplied by a separate H.V. circuit.



G_H = H.V. Generator
S_1 = Auxiliary breaker is high current circuit
$L_G\ L_D$ = Inductance in high current circuit
S_t = Control unit for triggering sphere gas F
$I_G\ V_G$ = Current and voltage in high circuit
$C_G\ R$ = Capacitance and resistance for regulating the natural frequency of high current circuit.
C_2 = Supply capacitance of H.V. circuit
G = Short circuit generator
T = Transformer in high current
B = Breaker under test
i_H = Current h.v. circuit.
F = Spark Gap
I_B = Breaker current : V_s = Voltage

Fig. 11.11 Brown Boveri's Synthetic Testing Circuit.

The circuit on the left side of the breaker under test B is high current circuit which consists of short-circuit generator IG, short-circuit transformer and also capacitor C_G and resistor R_G C_G and R_G control the natural frequency of high current circuit. The short-circuit power is supplied at a voltages V_s which corresponds to about 30 kV, this voltages is smaller than recovery V_s required for testing the specimen. The recovery voltage is supplied by a separate voltage circuit on the right side of breaker B.

The auxiliary breaker S_1 is opened simultaneously with the tested breaker B and a few microseconds before the current interruption (i_G) in breaker B, the spark gap is triggered by control S_t and the voltage V, is applied to breaker B.

The current i_H has a natural frequency of 500 Hz and an amplitude of one-tenth of that of current i_G. The currents are superimposed in current zero zone in such a way that during final 100 micro-seconds only current i_H is flowing through breaker under test B. The auxiliary breaker S_1 interrupts high current circuit from H.V. circuit before current $i_S = i_G + i_H$ is interrupted by breaker B and breaker B has to interrupt only current i_H. The restriking voltage across breaker B is, therefore, given by that of H.V. circuit.

11.17. SUBSTITUTION TEST

In oil circuit-breaker the current to be interrupted provides the internal sources of extinguishing energy. Therefore the arc duration depends upon the current to be interrupted *i.e.* for lower currents breaking time is more and for higher currents the breaking time is less. In subsitution test a number of tests at closely graduated capacities are conducted on the breaker with internal source of extinguishing energy. Characteristics of arc duration and current to interrupted are plotted (Fig. 11.12).

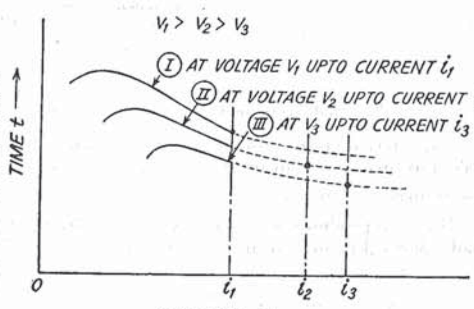


Fig. 11.12 Substitution test characteristics.

These are development tests.

The substitution test is conducted as follows :

(1) Test the breaker at full voltage and upto current permitted by the capacity of the plant, *i.e.* current i_1 of characteristic I.

(2) Test the breaker at reduced voltage upto current i_2 permitted by the test plant at reduced voltage V_2 obtain the time required for various current upto i_2 and plot characteristic II.

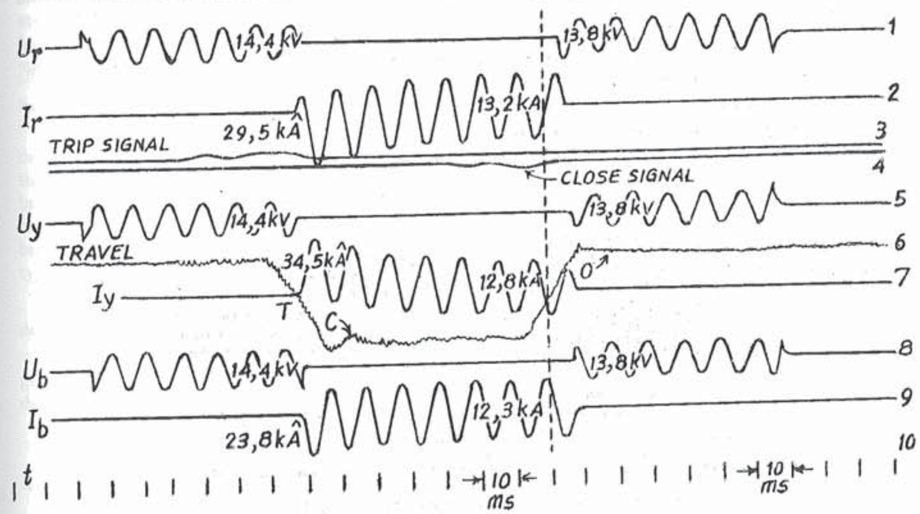


Fig 11.13. Record of 'C-O' operation during a short-circuit test on circuit-breaker.

Channels of U.V. Recorder :

U_r, U_y, U_b = Applied Voltages	3 = closing signal	I_r, I_y, I_b = Short-Circuit Current
4 = opening signal	T = Contact Travel	C = Closed
t = Timing marks	O = Open	

(3) Likewise, plot characteristics III at voltage V_3 upto current i_3, characteristic IV at voltage V_4 upto current i_1 etc where V_1 is the highest test voltage $V_1 > V_2 > V_3 > V_4$ etc. i_1 is the current at voltage V_1 permitted by test plant.

On plotting the characteristic I, II, III, etc, these are extended by approximation as shown by the dotted lines. Form the extended line the breaker performance can be predicated for values of current beyond range of testing station.*

11.18. CAPACITANCE TEST*

In this text a capacitor is charged by a d.c. voltage source. Capacitor is connected in series with an indcutor and making switch. The breaker is connected across the capacitor. C and L from oscillatory circuit. The circuit-breaker under test is opened and voltage across the capacitor is dis-

* These methods are used for development and research, and not for certification tests. These are not used by designers any more. The stresses occuring at full voltage and full current cannot be simulated by these tests.

Field Testing. The most convincing testing of circuit-breakers for proving capability of load switching without exceeding overvoltages is testing in actual installation. At least 30 switching operations should be carried out.

charged through the arc. The arc gets extinguished at a current zero. This test is used for investigating the behaviour of the breaker towards restriking voltage.

11.19. COMPENSATION TEST*

Oil circuit-breakers have internal source of extinguishing energy. For low currents extremely difficult extinguishing conditions may be experienced because of insufficient pressure build up. The characteristics of the breaker in critical range are ascertained by compensation test. These tests are conducted in critical range. In the test, the pressure in the arc extinction device, lengths and durations of arc etc. are recorded, test being conducted at reduced voltage. The reduction in voltage is compensated by some other factor such as :

(1) Increased frequency.

(2) Applying impulse voltage at current zero.

(3) The pressure in the tank of an oil circuit breaker is given by

$$p = kV^{0.5}I^{1.2}$$

The effect of reduced voltage can therefore be compensated by increasing current.

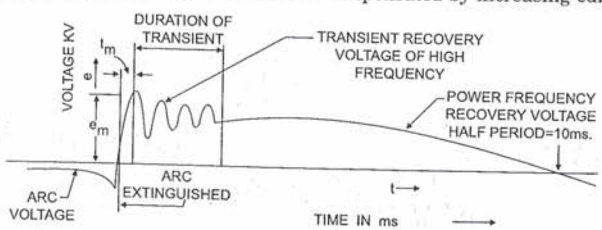


Fig. 11.14. Record of transient recovery voltage waveform on high speed CRO.

11.20. DEVELOPMENT TESTING OF CIRCUIT-BREAKERS

Table 10.2 to 10.4 gives a list of various development tests on a typical circuit-breaker.

Short-Circuit Development Tests : In earlier stages of circuit-breaker development the development tests were conducted on scaled models. Now, full scale prototype are subjected to development tests.

A complete programme of short-circuit development tests is drawn and adequate numbers of full scale prototypes are built. The important components in the interrupter such as contacts, nozzles etc. are made interchargeable.

The parameters which have a significant influence on the short-circuit performance of a circuit-breaker are identified. Their range is selected. For example, the diameters of contact may be in the range of 30 mm to 45 mm. In this case three to four contacts may be selected for development testing.

Three important parameters which determine the short-circuit performance of a circuit-breaker include.

1. Contact separation and the time-travel characteristic during opening operation.
2. Short-circuit current magnitude and its co-relation with the contact separation, speed and flow of quenching medium.
3. Arcing time and energy in arc. Parameters are varied and the performance of the circuit-breaker is analysed.

* These methods are used for development and research, and not for certification tests. These are not used by designers any more. The stresses occuring at full voltage and full current cannot be simulated by these tests. **Field Testing.** The most convincing testing of circuit-breakers for proving capability of load switching without exceeding overvoltages is testing in actual installation. At least 30 switching operations should be carried out.

Effect of Time-Travel Characteristic : The most important parameter is the time-travel characteristic during opening stroke and the number of current zeros. If speed is increased, the number of available current zeros during effective portion of travel is reduced. If speed is reduced the number of available current zeros is more, but the pressure in SF_6 puffer cylinder may be inadequate.

During development testing, the time-travel characteristic is optimized.

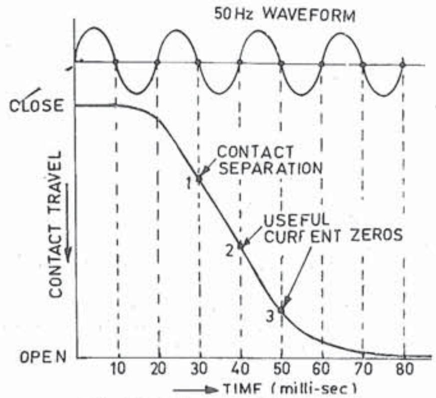


Fig. 11.15. Time-travel characteristic for opening stroke.

Summary

Short Circuit Tests provide a useful data for design and development of circuit-breakers and they are necessary to prove the making capacity, breaking capacity, breaking capacity, short time capacity and specified operating duty of the circuit breaker. The short circuit testing stations are filed type or laboratory type.

The number of useful current zeros, 1, 2, 3 depend upon the contact speed.

In laboratory type testing station there are specially designed equipments such as short circuit generators, short circuit transformers reactors master circuit breakers, making device etc. In addition there are equipment for measurements and control.

Direct tests are conducted according to Standard Specifications.

In unit testing one or more units are tested and from that the capacity of the complete breaking is ascertained.

In synthetic testing separate current source and voltage source and used for testing.

QUESTIONS

1. Why are short circuit necessary ? What information can be obtained from the short circuit tests ?
2. Describe with neat sketch the layout of a simple short circuit plant. Give details of equipment.
3. What is the difference between field testing and laboratory testing ? Explain the relative merits of each.
4. Describe the procedure of direct testing of a three phase circuit breaker for short circuit testing. Explain how is the making capacity, breaking capacity and short time capacity determined.
5. Explain the standard procedure of determining rate of rise of restriking voltage from a single frequency transient.
6. What is the difference between direct testing and indirect testing ? What are the various procedure of indirect testing ? Describe

   (*a*) Unit testing (*b*) Synthetic testing.
7. Calculate the natural frequency for a circuit having inductance 1.9 mH/km per phase capacitance 7.5 n F/km phase to earth, length of circuit 10 km.
8. With neat diagrams, explain the principle of synthetic testing.

   State the difference between 'Series Current Injection' and 'Parallel Current Injection'.