http://dx.doi.org/10.5370/JEET.2012.7.5.778

Three-phase Making Test Method for Common Type Circuit Breaker

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Abstract – The synthetic short-circuit making test to adequately stress the circuit breaker has been specified as the mandatory test duty in the IEC 62271-100. The purpose of this test is to give the maximum pre-arcing energy during making operation. And this requires the making operation with symmetrical short-circuit current that is established when the breakdown between contact gap occurs near the crest of the applied voltage. Also, if the interrupting chamber of circuit breakers is designed as the type of common enclosure or the operation is made by the gang operated mechanism that three-phase contacts are operated by one common mechanism, three-phase synthetic making test is basically required. Therefore, several testing laboratories have developed and proposed their own test circuits to properly evaluate the breaker performance. With these technical backgrounds, we have developed the new alternative three-phase making circuit.

Keywords: Circuit breaker, Synthetic making test, Pre-arcing performance, Symmetrical current, Asymmetrical current, Short-circuit current

1. Introduction

The circuit breaker used in the power system remains closed in the normal condition but if there are abnormal phenomena, it should be opened to protect other equipment. So if the short-circuit faults occur, the circuit breaker will interrupt the high current and make re-closing duty in order to discriminate whether the faults are caused by the instantaneous faults that can be recovered. This kind of operation is a part of rated operation sequence which is generally specified as 'O – 0.3 s – CO – 3 min – CO' or 'CO – 15 s – CO'. Where O represents an opening operation and CO represents a closing operation followed immediately by an opening operation of the circuit breaker. There is an intermediate re-closing time between opening and closing operation to wait clearance of fault. During the rated operation sequence, the circuit breaker is maintained in the closed position even though the faults have not been cleared and then it will be opened after specified time of the sequence.

The international standard [1] specifies the testing procedures to verify making performance of circuit breaker against the high short-circuit current. For medium-voltage class circuit breaker, the making performance can be properly verified during the rated operating sequence of test duty T100s (100 % short-circuit current) because the testing facilities, especially short-circuit generator, generally have the sufficient power enough to carry out all test duties with direct test method. However, for high-voltage class circuit breakers, alternative test methods are necessary because of limitation of testing facilities. Typical alternative method is synthetic test which is composed with combinations of current source and voltage source.

The international standard [1] for high-voltage circuit breaker mentions the extreme cases of making performance as follows:

- Making at the peak of voltage wave, leading to a symmetrical short-circuit current and the longest pre-striking arc;
- Making at the zero of the voltage wave, without pre-arcing, leading to a fully asymmetrical short-circuit current.

Eventually, the verification test for making performance should meet above two conditions because the pre-arc energy and the peak current(asymmetrical current) differently influence the breaker performance; the pre-arcing energy by symmetrical current makes the contact wearing higher and the electro-magnetic force by asymmetrical peak current gives the damages to the supporting and conducting part during closing operation. To get the maximum pre-arcing energy, the maximum peak voltage should be applied between contacts. Also to get the maximum dynamic force, the three-phase making current should be flow in all phases. The several test circuits for three-phase synthetic making operation have been developed [2, 3] but these circuits require three sets of synthetic making devices made up of gap switch, voltage source, initial transient making current(ITMC) circuit, auxiliary circuit breaker and etc. Therefore, several testing laboratories have developed and proposed their own testing circuits and facilities to properly evaluate the breaker

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Received: June 2, 2011; Accepted: June 11, 2012

performance. Also we have developed the new alternative three-phase making circuit to test the circuit breaker.

2. Making capability

2.1 Making operation

The circuit breaker is stressed by the applied voltage and current during the making operation. Typically, three intervals are introduced to characterize the making operation [2]; high-voltage interval, pre-arcing interval and latching interval.

The high-voltage interval is the time from the commencement of the test, with the circuit-breaker in the open position, to the moment of breakdown across the contact gap. The pre-arcing internal is the time duration between the initiation of current flow in the first pole during the closing operation and the instant when the contacts touch in all poles for three-phase conditions and the instant when the arcing contacts touch for single-phase conditions. The contacts of circuit breaker are under a lot of stress during this time. The latching interval is the time, during the closing operation of the circuit-breaker, from the touching of the contact to the moment when the contact reaches the fully closed (latched) position.

The dielectric strength of the contact gap of a closing circuit breaker is going to be reduced. This phenomenon can be linearized and then expressed to RDDS (Rate of Decay of Dielectric Strength) [3]. The breakdown will occur when RDDS line and applied voltage line (imaginary line) between contacts are met. The maximum pre-arcing time can be got when the pre-strike (breakdown) starts near the crest of the applied voltage. The pre-arcing time is the minimum when the pre-strike occurs near zero of the applied voltage. This kind of arc stress has impacts on both contact face and mechanical operation because of the elevation of gas pressure caused by arc energy.

The current initiated by pre-strike has only symmetrical component if the breakdown occurs near the crest of the applied voltage because the power system has mainly reactive circuit components. There will be asymmetrical component of the current if the breakdown occurs near zero of the applied voltage and maybe the maximum peak current will flow. For three-phase circuit breaker, especially having the gang operated mechanism, if the closing time is almost same and the pre-strike can be ignored in all phases, there are almost maximum asymmetrical current flow in one phase and symmetrical current flow in other phases. If the pre-arcing time is considered, there will be also asymmetrical current flow. The asymmetrical current impacts on mechanical operation because the highest dynamic forces are introduced between phases. Thus the circuit breaker should be closed and latched against the pressure caused by arc energy and dynamic force caused by magnitude of current.

2.2 Requirements on making performance

The regulations for making test can be found in following standards;

IEC 62271-100 [1] sub-clause 6.102.4.1: "The verification test for making consists of two three-phase making operations under the same condition ..."

STL guide for IEC 62271-100 [4] sub-clause 6.102.4.1 : "... a single-phase test with all the three poles electrically connected in series may be carried out.", "The three-phase verification test for making with full symmetrical current and maximum pre-arcing may be made with a three-phase current source at a reduced voltage combined with a single phase synthetic making circuit."

Based on above regulation, the three-phase current flow is required for three-phase circuit breaker and the specified voltage should be applied in the phase which in the maximum pre-arcing time can be achieved. The related standard for synthetic test [2] introduces the test circuit as below. It consists of two sources and the permissible time delay of making device is specified for this test circuit.

(1) The voltage circuit
- Supply the voltage during the high-voltage interval.
- Supply ITMC (Initial Transient Making Current) during the pre-arcing interval, by discharge of the ITMC-circuit.
- ITMC current shall be maintained to the instant that the power frequency current of current source is superimposed through the gap-switch (CH).

(2) The current circuit
- Supply the making current during the pre-arcing and latching intervals.

Also the time delay of making device (from pre-arcing to current flow) should be lower than 300 μs.

The Fig. 1 shows the single-phase synthetic test circuit. The ITMC circuit should have sufficient time constant to ensure that the current (I_t) should maintained during the time from initiation of pre-strike to the operation of making device (CH).

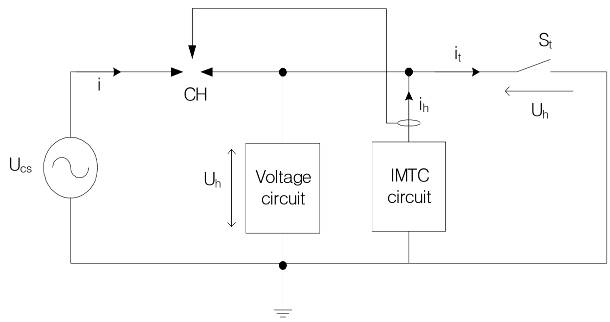

Fig. 1. Typical circuit for single-phase synthetic make test

With the same point of view, The Fig. 2 shows the three-phase synthetic test circuit with the first-pole-to-clear factor (K_{pp}) of 1.5. In case with K_{pp} of 1.3, the voltage circuit is a little bit different from this one. However, the standards permit that the test circuit with K_{pp} of 1.5 can cover both conditions of K_{pp}. The voltage circuit can be replaced to the capacitor bank with reactor to introduce oscillating voltage or without it to maintain dc voltage.

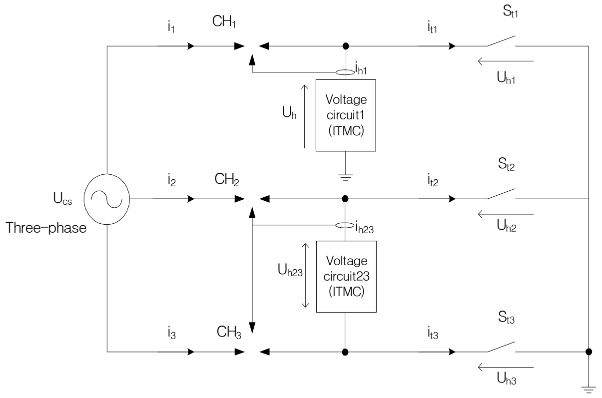

Fig. 2. Typical circuit for three-phase synthetic make test (k_{pp} of 1.5)

3. Alternative synthetic making test and limitation

3.1 Review of practical possible circuit

Two alternative test circuits for making test are suggested in the IEC standard [2] and STL guide [4], if three-phase making test is not possible to carry out due to the limited capacity of testing facilities. One is that all three poles are connected in series electrically and apply rated phase voltage to the single pole or three times of rated phase voltage to the three poles. Practically it is possible to apply three times of rated phase voltage because of the easiness of test circuit connection and the recovery of dielectric insulation in each phase. The Fig. 3 shows the test circuit for this test method. In this case, the pre-arcing performance by symmetrical current between contacts can equivalently be simulated because single-phase current flows into all three phases. While electromagnetic force by asymmetrical current between phases cannot be verified. Also, in case of dead-tank type breaker, voltage stress between live part and earthed enclosure is severer than that of three-phase making operation.

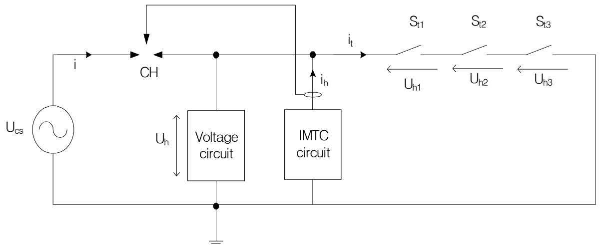

Fig. 3. Alternative circuit: all three poles are electrically connected in series

The other alternative method is that the three-phase current source is applied and the synthetic making circuit is connected to the single-phase. The Fig. 4 shows the test circuit for this test method. This test method is more appropriate than previous method because there will be three-phase current flow including symmetric current and asymmetric current.

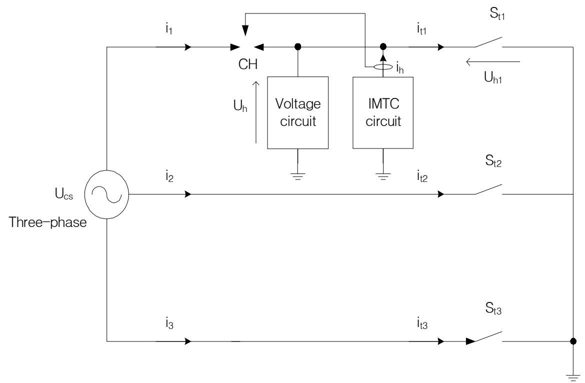

Fig. 4. Alternative circuit: three-phase current and single voltage

Practically above alternative circuit is difficult to adapt for K_{pp} of 1.5 which the neutral of supply or load side is earthed. If the pre-arcing time is longer compare to the time constant of ITMC circuit, ITMC cannot be continued to flow until contacts touch of two poles electrically.

For example, if the pre-arcing time is 2 ms and time constant of ITMC circuit is 300 us, the pre-arc is initiated at first in the pole which the rated phase voltage is applied to during the making operation. Then the small current supplied from ITMC circuit will flow into this pole. But this current will be decreased with time constant while the arc between contacts is maintained because generally ITMC circuit use resistor and capacitor circuit without current oscillation. At this time, this current is detected by appropriate sensor and this sensor is going to trigger plasma making switch (CH). Then the current source supplies three-phase test current with power frequency into the test breaker. In this state, there is no pre-arc by electrical contact touch in one of the other two poles and then the energy charged in ITMC circuit is exhausted and the arc initiated in first pole cannot maintain any more. Thus all poles recover its insulation and the current cannot flow in any poles until contact touch in two poles. Some later, the current will flow, but it cannot meet the requirement of standard that the arc should be initiated without current discontinuity near the crest of the applied voltage with ±15° tolerance. (±0.069 ms for 60 Hz, ±0.83 ms for 50)

3.2 Three-phase synthetic making test circuit developed

As an effective testing circuit to estimate both the pre-arcing performance and electro-dynamic performance during the three-phase making operation, We have developed the new alternative three-phase making test method to cover the circuit breaker up to rated on 3 phases 245 kV 63 kA. The Fig. 5 shows the circuit for this test method. It is similar with three-phase current and single voltage source circuit but there are some differences as follows:

(1) Voltage circuit is applied between phases. (which is step-up transformer)
(2) ITMC circuit is applied between phases. (which is RC series circuit)
(3) Earthing of test circuit is connected to supply side of the test breaker.
(4) Voltage distribution circuit is adopted between two phases. (which is combined with voltage circuit)

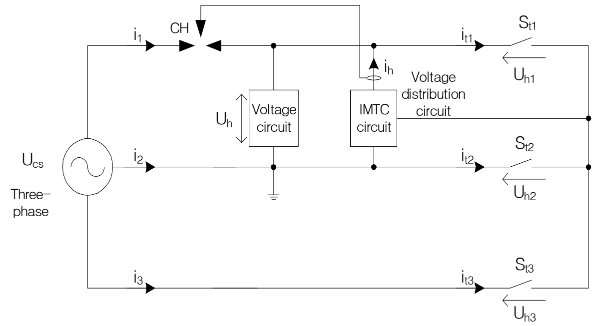

Fig. 5. Three-phase synthetic make test circuit developed

This circuit uses three-phase current source and a set of making test device such as plasma making switch, step-up transformer, ITMC(Initial Transient Making Current) circuit and auxiliary breaker. Because the neutral of current source and load side of test breaker are not earthed, special consideration may be needed to ensure the circuit insulation.

Test procedure and operation of this test circuit are as follows:

(1) The voltage circuit applies voltage between phases (2 times rated phase voltage = U_h).
(2) The charged voltage in ITMC circuit is applied to S_{t1} and S_{t2} in series.
(3) The voltage distribution circuit regulates this voltage to two poles (S_{t1} and S_{t2}) according to the ratio (maybe $0.5U_h$ in each pole).
(4) ($0.5U_h$ - $U_{cs.phase\ 3}$) is applied to the other pole (S_{t3})
(5) The source phase voltage of phase 3 ($U_{cs.phase\ 3}$) is very small compare to the U_h. Thus, the voltage between S_{t3} is almost $0.5U_h$. (a little small)
(6) The applied voltage in all three poles is same except the polarity and the pre-arc during the making operation may be initiated at the same time.
(7) The invalid test caused by insulation recovery will not happen.
(8) If the pre-strike occurs near the crest of the applied voltage in two phases (or all three phases), the current from ITMC circuit will flow.
(9) The sensor will detect i_h and trigger plasma making switch (CH) within 300 us.
(10) The current including symmetric and asymmetric components in all three phase will flow.

The direction of the current I_{t1} and I_{t3} is from current source to short-circuit point (secondary position of test breaker). The current I_{t2} is the opposite direction of the sum of I_{t1} and I_{t3}. These currents are three-phase, thus the currents in all three phases are exactly same with the direct three-phase making circuit. (Refer to the Fig. 6).

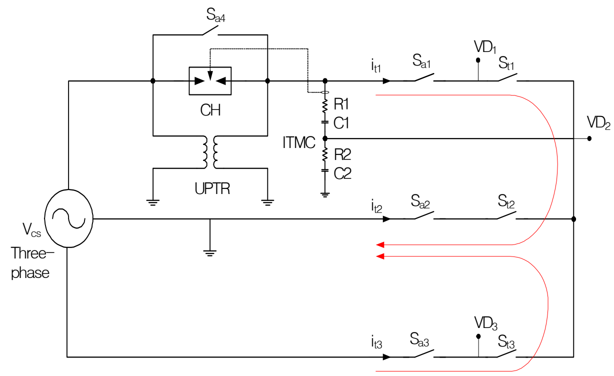

Fig. 6. Practical application circuit and measuring position

Line-to-line and line-to-enclosure of the test breaker should withstand two times rated phase voltage because this voltage is applied to the front of S_{t1}. The locations for voltage measurement are appeared in Fig. 6. Two dividers in front of S_{t1} and S_{t3} and one divider on short circuit point of test breaker are located to minimize the number of voltage dividers. The voltages between contacts are calculated as bellows:

$$U_{h1} = VD_1 - VD_2$$
$$U_{h2} = -VD_2$$
$$U_{h3} = VD_3 - VD_2$$

3.3 Application to making test of proposed circuit

Table 1. Parameters for test circuit

Test circuit parameters for 145 kV, 40 kA Current source : 8.2 kV, 40 kA Voltage source : UPTR ratio = 20.5 ITMC circuit : 2 set of R = 3 kΩ, C = 110 nF
Test circuit parameters for 170 kV, 50 kA Current source : 12.3 kV, 50 kA Voltage source : UPTR ratio = 16.0 ITMC circuit : 2 set of R = 3 kΩ, C = 110 nF

By using the proposed circuit, the tests on two kinds of breaker are performed on the dead-tank type GCB rated on 170 kV, 50 kA, 60 Hz with common enclosure and the live-tank type GCB rated on 145 kV, 40 kA, 50 Hz with gang operation mechanism.

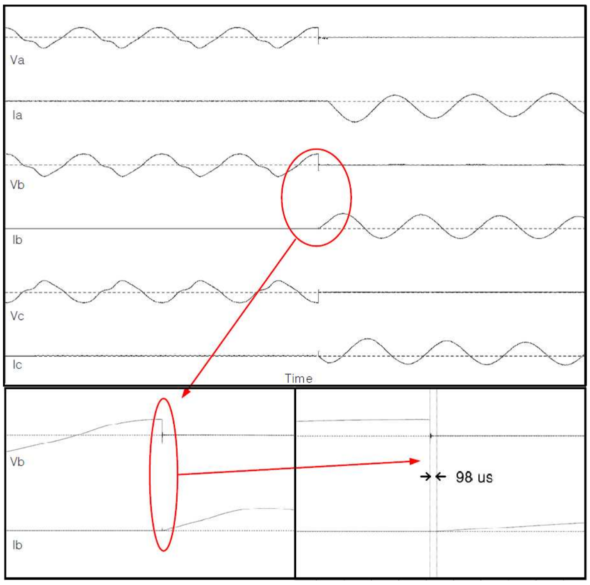

Fig. 7. Test result on 145 kV, 40 kA GCB

Fig. 7 shows the result of making test on 145 kV, 40 kA GCB. The pre-strike is initiated near the crest of the applied voltage in phase B and C and current asymmetry was also obtained. The oscillogram shows that there is no insulation recovery phenomenon and the current flows in all phases. Right-below oscillogram shows that the time delay from the pre-strike to the start of current flow is about 98 us. This is lower than specified value 300 us in the standard.

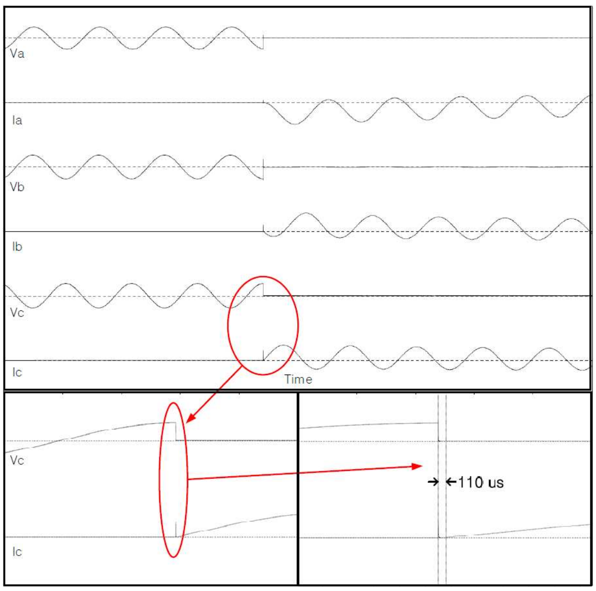

Fig. 8. Test result on 170 kV, 50 kA GIS

Fig. 8 shows the result of making test on live-tank type GCB rated on 170 kV, 50 kA. The pre-strike was initiated near the crest of the applied voltage in all three phases and current asymmetry was also obtained. There is no insulation recovery phenomenon and the current flow in all phases. The time delay from the pre-strike to the start of current flow is about 110 us.

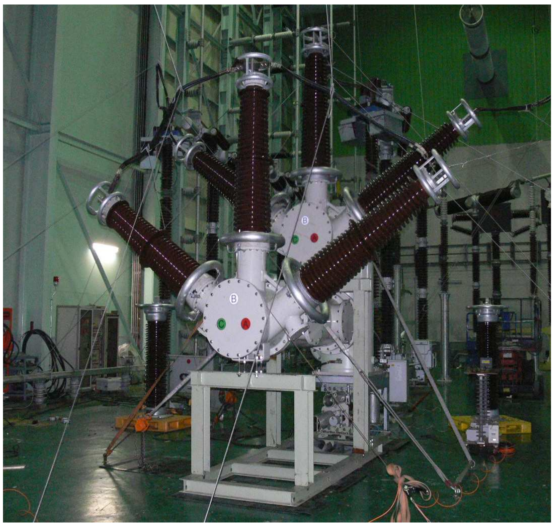

Fig. 9. Test breaker after three-phase synthetic making test

4. Conclusion

Other alternative test circuit for three-phase making test has already developed and verified [3]. Other alternative method have also suggested due to the limitation of test facilities [2, 4]. But some modifications of test circuit are required. Therefore, several testing laboratories have developed and proposed their own testing circuits and facilities to properly evaluate the making performance of the circuit breaker. The main focus for them is to have the equivalence with the three-phase making operation that consist of symmetrical current to give the maximum pre-arcing energy and asymmetrical current to give the maximum electro-dynamic force. With these technical backgrounds, we have developed the new alternative three-phase making test circuit. This circuit uses minimum number of voltage circuit, measuring device for current and voltage, plasma making switch and auxiliary breaker. Using this test circuit for high-voltage circuit breaker is suitable. But special consideration should be required for the test of dead tank GCB intended for GIS (gas insulated switchgear) because two times rated phase voltage is applied between line and enclosure. But this voltage level is within AC power frequency capability of the circuit breaker and this method can be regarded with the effective method.

Acknowledgements

The authors are pleasure to express thanks to Mr. Cho, Yun-Ho of Changwon Plant H.V Switchgear R&D Team, Hyosung Corporation who gave permission for the use of their test result and photograph.

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