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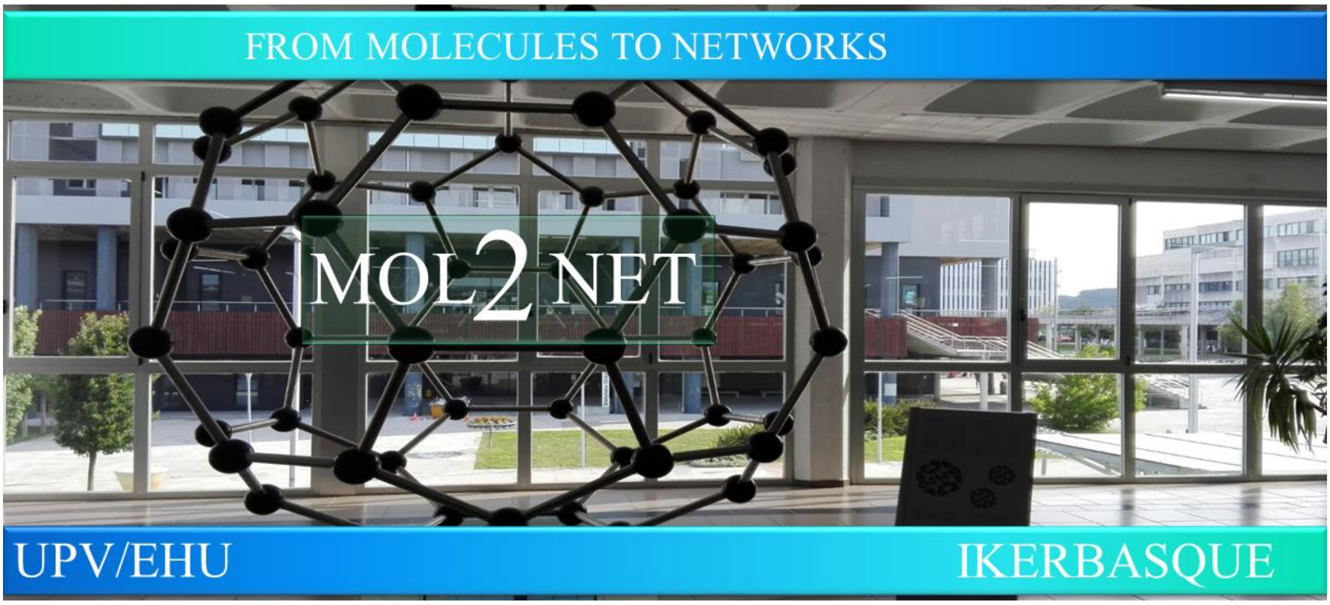

The investigation of crucial tests for medium voltage vacuum circuit breaker

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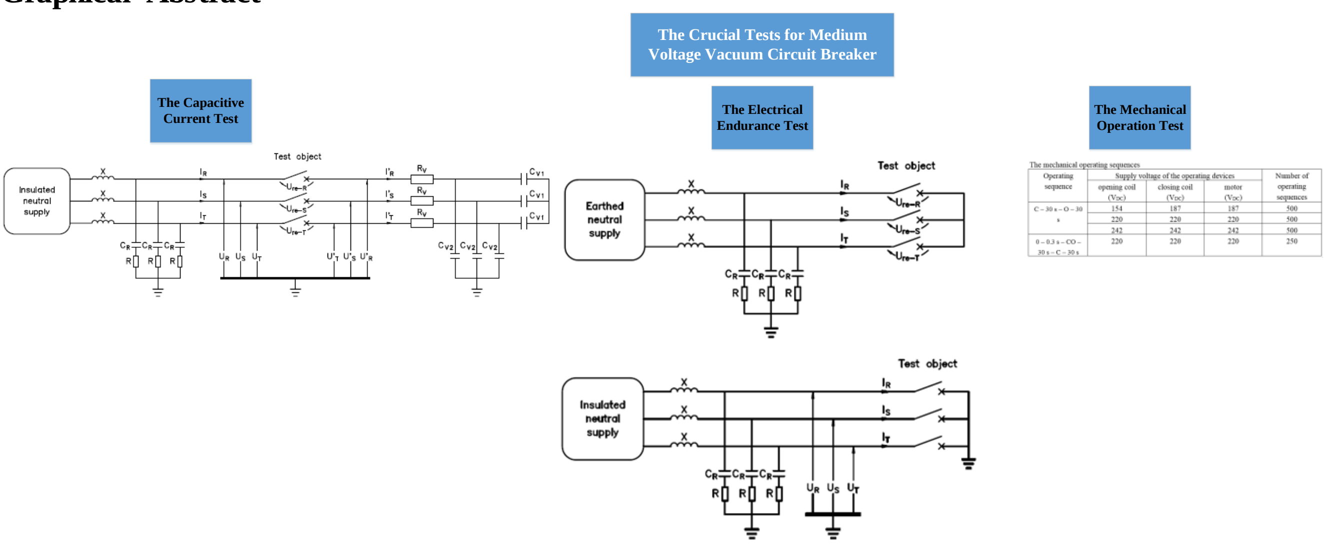
Graphical Abstract



Abstract

Because of the harmful effect of the environment, the use of SF_6 is restricted and its alternatives are investigated. Among those alternatives, vacuum circuit breaker gain a crucial role at mostly in medium voltages. In this study, the capacitive current test, electrical endurance test and mechanical operation test are investigated among why they are crucial and what those means with the insulation way of thinking.

Introduction

Vacuum circuit breakers (V.C.B.) are the leading technology used worldwide today for medium voltages up to 52 kV. Thanks to vacuum-switching technologies that have been used since the late 1960s, millions of vacuum circuit breakers have been produced over time [1]. Due to the known environmental effects of SF_6 causing global warming, the search for alternative insulated circuit breakers continues [2-4]. Vacuum circuit breakers are seen as the leading candidate to replace SF_6 [5]. Vacuum circuit breakers are mechanically the simplest circuit breaker [6]. They consist of only a fixed and movable contact located in a vacuum bottle. When the contacts separate, the arc is supported by ionized metal vapor released from the cathode or negative contact that thus supplies the arcing medium. When the current approaching zero, the collapse of ionization and the condensation of vapor is very fast, ensuring efficient current interruption, virtually independent of the rate of rise of the transient recovery voltage (TRV). Vacuum interrupters need no supply of gasses and liquids so they are not flammable and emit no flame or hot gas. Because of the absence of inelastic collisions between the gas molecules, vacuum has the fastest recovery strength after arc interruption at current zero so there is no avalanche mechanism to trigger the dielectric breakdown as in gasses. Therefore, vacuum circuit breakers need no capacitors or resistors to interrupt short line faults. Because of short arcing times, small contact gap and arc length, the arc energy dissipated in vacuum is approximately one-tenth of that in SF_6 and even less than that of oil. The low arc energy keeps the contact erosion to a minimum [7]. Vacuum circuit breakers need relatively little mechanical energy to operate, at least compared to others and allows simple, reliable, and silent operating mechanisms. In this study, the mechanical operation test of the vacuum circuit breaker will be examined in detail. The tests were carried out in accordance with the relevant IEC standard [8]. Uncertainties in measurement were determined according to JCGM100:2008 [9].

The crucial tests for medium voltage vacuum circuit breaker:

A. The Capacitive Current Test:

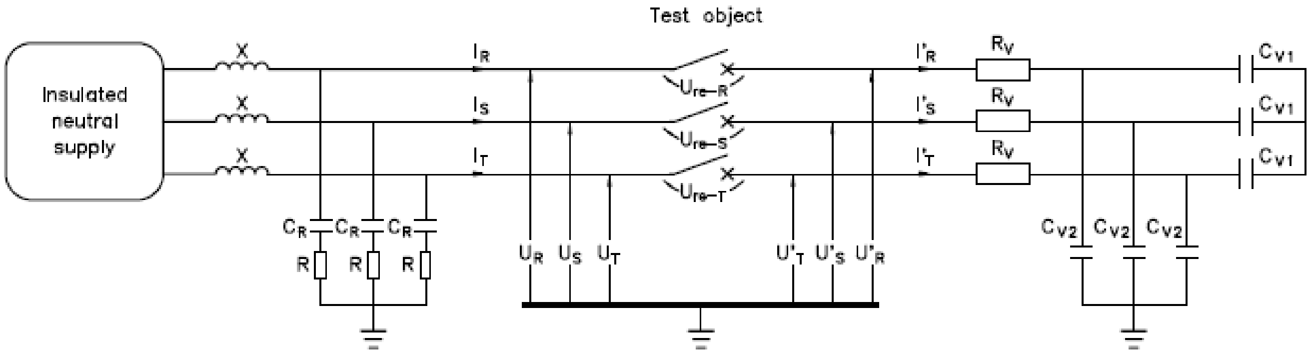


Figure 1. Test setup for capacitive current test

The test setup in Figure 1 was used for capacitive current tests, which are line and cable charging current interruption tests of the vacuum circuit breaker examined within the scope of this study. The measurements are taken according to IEC 62271-100:2021 standard. The vacuum circuit breaker designed and produced by Armtek Electric Inc. with nominal voltage and current of 36 kV and 1250 A, respectively, is used as the test object.

If there is no load or very little load at the end of the line, a capacitive situation occurs. This test is to verify that the vacuum circuit breaker can operate smoothly even in this capacitive situation that may arise. The most challenging test for a vacuum circuit breaker is the capacitive current test.

During these tests, three different test cycles are applied. The first test cycle is three-phase cable and line charging current switching tests; the current is 50.5 A, and the voltage is 36.1 kV. C_{V1} capacitance in the load circuit is 6.65 µF, C_{V2} capacitance is 0.53 µF, R_v resistance is 22 Ω. Process order: first closing and then opening, and the test is repeated 24 times.

The second test cycle is the three-phase cable charging current switching test, the current is 17.5 A, the voltage is 36.1 kV. C_{V1} capacitance in the load circuit is 2.15 µF, C_{V2} capacitance is 0.53 µF, R_v resistance is 22 Ω. This test, in which the opening process is performed, is repeated 24 times.

The third test cycle is the three-phase cable charging current switching test, the current is 2.88 A, the voltage is 36.1 kV. C_{V1} capacitance in the load circuit is 0.35 µF, C_{V2} capacitance is 0.11 µF, R_v resistance is 11.25 Ω. This test, in which the opening process is performed, is repeated 24 times.

An external visual inspection before and after each test cycle checks whether the vacuum circuit breaker can continue testing. A vacuum circuit breaker found to be damaged (explosion, burn marks, etc.) by the tests performed during these visual external inspections is recorded and prevented from further testing. Before and after testing, photos of the vacuum circuit breaker are taken. During the examination, it was determined that the vacuum breaker was not damaged during the test and was usable and in working condition after the test. In all tests, the tests were successfully passed since no restrike of the current occurred during the breaking operations.

B. The Electrical Endurance Test

The test setup for test duties T10, T30, and T60 can be seen in Figure 2, while the test setup for test duty T100s is shown in Figure 3.

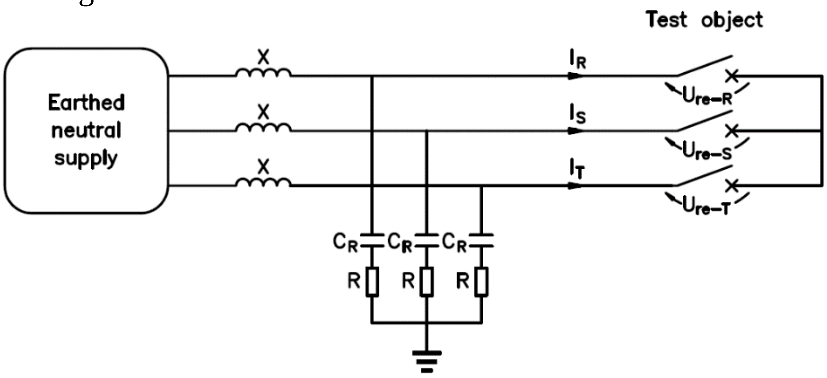


Figure 2. The test setup for test duties T10, T30, and T60

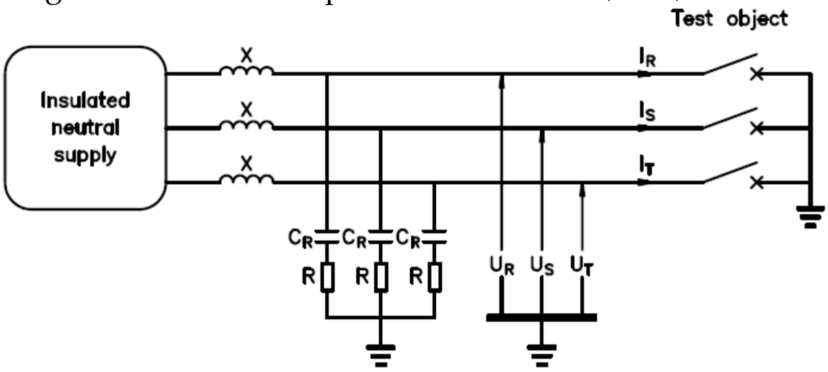


Figure 3. The test setup for test duty T100s

The vacuum circuit breaker designed and produced by Armtek Electric Inc. with nominal voltage and current 24 kV and 1250 A, respectively, is used as the test object.

Table 1: The three-phase electrical endurance tests

Test:	The phase-to-phase power frequency recovery voltage (kV)	The a.c. component r.m.s. value of the breaking current (kA)
T10	24	3.15
T30	24.4	9.70
T60	24.6	18.70
T100s	24.2	31.50

The vacuum circuit breaker was inspected for damage before and after each test cycle. The important thing is that the vacuum circuit breaker operates smoothly without encountering any problems with the applied voltage and current, so has successfully passed the electrical endurance tests.

C. The Mechanical Operation Test

The vacuum circuit breaker designed and produced by Armtek Electric Inc. with nominal voltage and current 24 kV and 2500 A, respectively, is used as the test object.

The importance of this test is to prove that the vacuum circuit breaker can operate smoothly even after operating 10,000 cycles.

The test sequence listed in the below Table 2 has been repeated for five times, for a total of 10,000 operating cycles. The check of the characteristics has been effected after each set of 2000 operating cycles.

Table 2: The mechanical operating sequences

Operating sequence	Supply voltage of the operating devices			Number of operating sequences
	opening coil (V_{DC})	closing coil (V_{DC})	motor (V_{DC})	
C – 30 s – O – 30 s	154	187	187	500
	220	220	220	500
	242	242	242	500
0 – 0.3 s – CO – 30 s – C – 30 s	220	220	220	250

1. Operating sequence: First, the closing operation is performed, and then, after waiting for 30 seconds, the opening operation ise performed. Then waiting for 30 seconds.
2. Operating sequence: First, the opening operation is performed, and then, after waiting for 0.3 seconds, the closing and opening operations are performed. Then, after waiting for 30 seconds, the closing operation is performed and waiting for 30 seconds.

The test object was checked for its characteristics before the tests. Motor peak and steady state current, duration of the operation and operation time of main contacts are measured with different supply voltage of operating devices.

After that, the rated operating sequence was verified before the tests. First, the opening operation is performed, and then, after waiting for 0.3 seconds, the closing and opening operations are performed. Finally, after waiting for 3 minutes, the closing and opening operations are performed.

After each 2000 operating cycle, the characteristics of the tested object were checked. Even if the number of operating cycles increases, the measured values do not change much. This shows that the vacuum circuit breaker performs consistent and stable operation.

After 10,000 operating cycles, it was verified that the vacuum circuit breaker worked properly. After 10,000 operating cycle, the final curve is in the +/- 5% limits of reference curve so this test was completed successfully.

Resistance measurement of contacts and connections in the main circuit as a condition check was performed according to subclause 7.4.4 of the IEC 62271-1 (2017-07) standard, and it was found that there was little change in the resistance values before and after the test so this part was completed successfully.

The voltage test were performed according to IEC 62271-100 standard clause 7.2.12, after 10,000 operating cycles and the vacuum circuit breaker withstands both test configurations, so it passed the voltage test.

Conclusions

The primary purpose of a vacuum circuit breaker is to protect power system equipment when a fault occurs. When a trip signal is sent to the vacuum circuit breaker following fault detection, this switching equipment must interrupt the fault current with 100% reliability. The dielectric strength of the vacuum environment is considerably higher than that of circuit breakers using gas insulators. Compared to other circuit breakers, the mechanical power required to open and close the contacts is significantly reduced, and the mechanism interrupting the fault differs.

This study aims to examine the capacitive current test, the electrical endurance test and the mechanical operation test, the three most important tests performed on medium-voltage vacuum circuit breakers. Thus, its stable and trouble-free operation has been proven by operating in capacitive currents with the capacitive current test, in specified voltage and current with the electrical endurance test, and in 10,000 operating cycles with the mechanical operation test.

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