Research Article

Investigation of Three-Phase Electrical Endurance Test Results of Vacuum Circuit Breaker

Seyit Ali Ceyhuni[1], Huseyin Uc[2], Orkun Kilic[3], Ahmet Ocak[4], Hidir Duzkaya[5], Suleyman Sungur Tezcan[6*]

[1]Armtek Electric Inc., Orcid ID: https://orcid.org/0009-0000-0137-3894, ali.ceyhuni@armtek.com.tr,
[2]Armtek Electric Inc., Orcid ID: https://orcid.org/0009-0005-5903-3039, huseyin.uc@armtek.com.tr,
[3]Armtek Electric Inc., Orcid ID: https://orcid.org/0009-0002-6830-1929, orkun.kilic@armtek.com.tr,
[4]Armtek Electric Inc., Orcid ID: https://orcid.org/0009-0007-4705-4670, ahmet.ocak@armtek.com.tr,
[5]Gazi University, Faculty of Engineering, Department of Electrical and Electronics Engineering, Orcid ID: https://orcid.org/0000-0002-2157-0438, hduzkaya@gazi.edu.tr,
[6]Gazi University, Faculty of Engineering, Department of Electrical and Electronics Engineering, Orcid ID: https://orcid.org/0000-0001-6846-8222, stezcan@gazi.edu.tr,
* Correspondence: stezcan@gazi.edu.tr; +90 533 394 62 91

(First received September 23, 2023 and in final form December 27, 2023)

Reference: Ceyhuni, S., A., Uc, H., Kilic, O., Ocak, A., Duzkaya, H., Tezcan, S., S. Investigation of Three-Phase Electrical Endurance Test Results of Vacuum Circuit Breaker. The European Journal of Research and Development, 3(4), 186-194.

Abstract

Instead of medium voltage breakers that use SF_6 gas, which has a global warming potential of 23,500 times more than CO_2 in a 100-year equivalent, the modeling and production of vacuum medium voltage breakers that can operate at different rated currents without any environmental damage is gaining importance. The issue of restricting the use of SF_6 gas through international agreements since the 1990s is becoming an obligation rather than a recommendation every day. This situation makes it necessary to develop products using SF_6 alternative insulating media in power system equipment for national and international markets. In this study, the electrical endurance tests for class 2 vacuum circuit-breakers for auto-reclosing are investigated. 10, 30, 60, and 100% rated short-circuit breaking currents are applied with different operating sequences.

Keywords: Vacuum circuit breaker, Three-phase electrical endurance test

1. Introduction

Vacuum circuit breakers (Vacuum Circuit Breakers, VCB) are the dominant technology worldwide for medium voltages up to 52 kV today and are seen as the leading candidate to replace SF_6. Vacuum switching technology was introduced in the late 1960s, and millions of vacuum circuit breakers have been produced since then [1]. Today, more than one million vacuum circuit breakers are produced every year. The main reason for this production success is the vacuum contact design and technology that has the capacity to extinguish arcs occurring in medium voltage networks, which are more compact and cost-effective than their counterparts. This technology is based on the principle of damping the arcs that occur during opening and closing operations in the Vacuum Interrupter (VI).

In vacuum tubes used in medium voltage networks, arcs formed under 9 kA cutting currents follow a dispersed geometry, and the energy of the arc is distributed evenly over the contact surface. This inherently makes the cutting process more manageable. At values greater than this limit cutting current, the arc geometry changes, and the arc occurs in a minimal contact surface area. In this case, contact overheats, metal vapor forms, and high pressure values are observed. As the current approaches zero, the collapse of ionization and condensation of the metal vapor is very rapid, providing efficient current interruption almost independently of the rate of rise of the transient recovery voltage (TRV).

Due to the known environmental effects of SF_6 causing global warming, the search for alternative insulated circuit breakers continues [2-4]. Compared to SF_6 alternatives, vacuum breakers stand out with their ability to switch up to 100 thousand times, provide an improved dielectric strength environment with faster recovery time, and withstand higher breaking currents (up to 200kA), in addition to not having any harmful effects on the environment [5]. Since vacuum tubes do not require any gas or liquid insulator for insulation, they do not show flammable character during the arc or emit flame or hot gas. Due to the absence of inelastic collisions between gas molecules, the vacuum has the fastest post-arc recovery time. It does not develop any avalanche mechanism that disrupts the characteristics of the insulating medium as in gases. Thus, vacuum circuit breakers do not require capacitors or resistors to interrupt short-line faults. Due to the short arcing times, small contact gap, and arc length, the arc energy emitted in vacuum is approximately one-tenth of that in SF6. Thanks to the low arc energy, contact wear in the vacuum circuit breaker is observed at a minimum level. The performance of vacuum circuit breakers in interrupting and protecting an electrical power system largely depends on the conditions of the contact surface between the contacts [6, 7]. Considering that the scope of national and international legislation to limit the use of SF_6 due to its global warming potential is expanding daily, vacuum circuit breakers are becoming an essential alternative in medium voltage distribution networks. Three-phase electrical endurance tests are required for each circuit breaker. This study examines the results of three-phase electrical endurance tests of the 24 kV 1250 A medium voltage vacuum circuit breaker.

2. Experimental Studies

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. This circuit breaker's opening and closing units are designed to be maintenance-free throughout its operating life (E2 class). The possibility of the current restarting when cutting the capacitive current is very low (C2 class). The on-off test was mechanically repeated 10 thousand times, and this test was successfully passed (M2 class). The circuit breaker class is S1, so the circuit breaker is intended to be used in a cable system.

The electrical durability tests of the vacuum breaker examined within the scope of this study were carried out by CESI S.p.A., an internationally accredited company based in Italy. Tests were carried out following the relevant IEC standard [8]. The test setup for test duties T10, T30, and T60 can be seen in Figure 1, while the test setup for test duty T100s is shown in Figure 2. For measurement, 12 different transducers with receiver and transmitter optical links, a data acquisition system, an oscilloscope, a micro ohmmeter, a digital chronometer and a digital multimeter were used. Uncertainties in measurement were determined according to JCGM100:2008 [9].

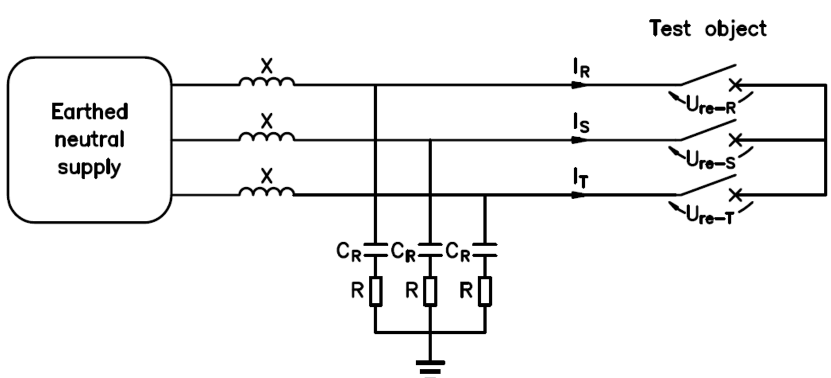

Figure 1: The test setup for test duties T10, T30, and T60

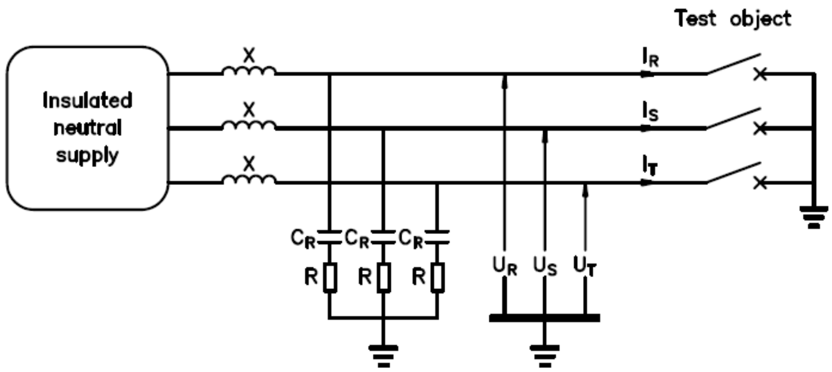

Figure 2: The test setup for test duty T100s

3. Investigation of Test Results

The three-phase electrical endurance tests, test duty T10, are applied three times, as shown in Table 1. The phase-to-earth and phase-to-phase power frequency recovery voltages are 13.9 and 24.0 kV, respectively, and the a.c. component r.m.s. value of the breaking current is 3.15 kA. 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.

The test circuits are connected to the main busbars in all tests. After all the tests, external inspections are made, and it is checked whether the apparatus is deemed to be able to continue the tests. As can be seen from the Tables 1-4, the closing, make, opening, arcing, and break times are measured. Which phase cleared the arc first was also written in the relevant tables in the arcing time section.

Table 1: The three-phase electrical endurance tests, test duty T10

Operating sequence	Applied Voltage Phase to Earth (kV)	Breaking current a.c. component r.m.s. value (kA)	Phase to earth Power frequency recovery voltage (kV)	Maximum overvoltage (kV)	Closing time (ms)	Make time (ms)	Opening time (ms)	Arcing time (ms)	Break time (ms)
Test no:1 O	-	3.15 3.15	13.9 13.9	49.8	-	-	27	8-T	35

		3.15	13.9						
Test no:2 0.3s CO	13.9 13.9 13.9	3.15 3.15 3.15	13.9 13.9 13.9	50.4	58	58	27	10-T	37
Test no:3 3min CO	13.9 13.9 13.9	3.15 3.15 3.15	13.9 13.9 13.9	50.0	59	59	28	10-R	38

The three-phase short-circuit tests, test duty T30, are applied three times, given in Table 2. The phase-to-earth and phase-to-phase power frequency recovery voltages are 14.1 and 24.4 kV, respectively, and the a.c. component r.m.s. value of the breaking current is 9.70 kA. The condition of the apparatus before the tests is as after test no. 3.

Table 2: The three-phase short-circuit tests, test duty T30

Operating sequence	Applied Voltage Phase to Earth (kV)	Breaking current a.c. component r.m.s. value (kA)	Phase to earth Power frequency recovery voltage (kV)	Maximum overvoltage (kV)	Closing time (ms)	Make time (ms)	Opening time (ms)	Arcing time (ms)	Break time (ms)
Test no:4 O	-	9.70 9.70 9.70	14.1 14.1 14.1	45.6	-	-	27	8-T	35
Test no:5 0.3s CO	14.1 14.1 14.1	9.70 9.70 9.70	14.1 14.1 14.1	46.0	57	57	28	7-S	37
Test no:6 3min CO	14.1 14.1 14.1	9.70 9.70 9.70	14.1 14.1 14.1	47.0	58	58	27	7-T	34

The three-phase electrical endurance tests, test duty T60, are applied sixty times, as seen in Table 3. The phase-to-earth and phase-to-phase power frequency recovery voltages are 14.2 and 24.6 kV, respectively, and the a.c. component r.m.s. value of the breaking current is 18.7 kA. Tests no. 7 to 66 are done with this test period, and it isn't easy to provide the exact table, so only the last three tests (test no. 64, 65, and 66) are given. The condition of the apparatus before the tests is as after test no. 6.

Table 3: The three-phase short-circuit tests, test duty T60

Operating sequence	Applied Voltage Phase to Earth (kV)	Breaking current a.c. component r.m.s. value (kA)	Phase to earth Power frequency recovery voltage (kV)	Maximum overvoltage (kV)	Closing time (ms)	Make time (ms)	Opening time (ms)	Arcing time (ms)	Break time (ms)
Test no:64 O	-	18.2 18.2 18.2	14.2 14.2 14.2	44.2	-	-	27	7-S	34
Test no:65 0.3s CO	14.2 14.2 14.2	19.0 19.0 19.0	14.2 14.2 14.2	44.7	56	55	28	6-S	34
Test no:66 3min CO	14.2 14.2 14.2	19.0 19.0 19.0	14.2 14.2 14.2	44.3	56	55	27	7-T	34

The three-phase electrical endurance tests, test duty T100s, are applied six times, given in Table 4. The phase-to-earth and phase-to-phase power frequency recovery voltages are 14.0 and 24.2 kV, respectively, and the a.c. component r.m.s. value of the breaking current is 31.5 kA.

Table 4: Three-phase short-circuit tests, test duty T100s

Operating sequence	Applied Voltage Phase to Earth (kV)	Breaking current a.c. component r.m.s. value (kA)	Phase to earth Power frequency recovery	Maximum overvoltage (kV)	Closing time (ms)	Make time (ms)	Opening time (ms)	Arcing time (ms)	Break time (ms)

			voltage (kV)						
Test no:67 O	-	31.5 31.5 31.5	14.0 14.0 14.0	43.5	-	-	27	9	37
Test no:68 0.3s CO	14.2 14.2 14.2	31.5 31.5 31.5	14.0 14.0 14.0	43.4	57	56	28	12	40
Test no:69 3min CO	14.2 14.2 14.2	31.5 31.5 31.5	14.0 14.0 14.0	42.0	58	57	28	8	36
Test no:70 O	-	31.5 31.5 31.5	14.0 14.0 14.0	42.5	-	-	28	9	37
Test no:71 0.3s CO	14.2 14.2 14.2	31.5 31.5 31.5	14.0 14.0 14.0	43.6	57	56	28	9	37
Test no:72 3min CO	14.2 14.2 14.2	31.5 31.5 31.5	14.0 14.0 14.0	43.4	59	58	28	10	38

The photos before and after the test are shown in Figure 3. As evident from these photographs, no damage occurred to the vacuum breaker during the tests.

a)

b)

c) d)

Figure 3: a) and b) The photos before the test, c) and d) The photos after the test

4. Discussion and Conclusion

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 a 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 types of circuit breakers, the mechanical power required to open and close the contacts is significantly reduced, and the mechanism used to interrupt the fault is different.

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. When the results obtained are examined, it is seen that the vacuum circuit breaker operating in medium voltage networks with rated voltage and current of 24 kV and 1250 A, respectively, has successfully passed the electrical endurance tests.

References

[1] Falkingham, L.T., "The strengths and weaknesses of Vacuum Circuit Breaker technology", 2011 1st International Conference on Electric Power Equipment - Switching Technology, 2011, 701-703. https://doi.org/10.1109/ICEPE-ST.2011.6122975.

[2] Dincer, S., Tezcan, S.S., Duzkaya, H., Dincer, M.S., "Insulation and Molecular Properties of Alternative Gases to SF6", 2018 2nd International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT), 2018, 1-4. https://doi.org/10.1109/ISMSIT.2018.8566680.

[3] Tezcan, S.S., Duzkaya, H., Dincer, M.S., Hiziroglu, H.R., "Assessment of electron swarm parameters and limiting electric fields in SF6+CF4+Ar gas mixtures", IEEE Transactions on Dielectrics and Electrical Insulation, cilt. 23, no. 4, ss. 1996-2005, 2016. https://doi.org/10.1109/TDEI.2016.7556471.

[4] Tezcan, S.S., Akcayol, M., Ozerdem, O.C., Dincer, M.S., "Calculation of Electron Energy Distribution Functions From Electron Swarm Parameters Using Artificial Neural Network in SF6 and Argon", IEEE Transactions on Plasma Science, cilt. 38, no. 9, ss. 2332-2339, 2010. https://doi.org/10.1109/TPS.2010.2049588

[5] König, D., "The role of vacuum in circuit breaker technology," 2012 25th International Symposium on Discharges and Electrical Insulation in Vacuum (ISDEIV), 2012, A1-A14. https://doi.org/10.1109/DEIV.2012.6412366

[6] Geng, Y. et al., "A New Measurement Method of Contact Conditions in a Vacuum Circuit Breaker With the Field Emission Current During the Closing Operation", IEEE Transactions on Instrumentation and Measurement, cilt. 71, ss. 1-11, 2022. https://doi.org/10.1109/TIM.2022.3193710

[7] Razi-Kazemi, A.A., Fallah, M.R., Rostami, M., "A Hybrid-Approach for Realtime Assessment of the Pressure and Erosion in Vacuum Circuit Breakers", IEEE Transactions on Dielectrics and Electrical Insulation, cilt. 27, no. 6, ss. 2087-2094, 2020. https://doi.org/10.1109/TDEI.2020.008577

[8] High-voltage switchgear and controlgear - Part 100: Alternating current circuit-breakers (IEC 62271-100:2021), European Committee for Electrotechnical Standardization, Brussels, 2021. https://webstore.iec.ch/publication/62785

[9] JCGM 100:2008, Evaluation of measurement data — Guide to the expression of uncertainty in measurement, 2008. https://www.bipm.org/documents/20126/2071204/JCGM_100_2008_E.pdf/cb0ef43f-baa5-11cf-3f85-4dcd86f77bd6