Synthetic Tests of Vacuum Circuit Breakers

V.A. Lavrinovich, S.N. Perepelkin

Tomsk Polytechnic University, 30, Lenin Avenue, Tomsk, 634034, Russia,
f. 42-38-38, E-mail: admin@hvd.tpu.ru

Abstract – The results of electro-discharge processes in vacuum arc interrupters on the developed and constructed synthetic test stand are described. The stand ensures a current amplitude up to 100 kA with a duration of 10 ± 1 ms at a voltage up to 5 kV and an amplitude of transient recovery voltage up to 40 kV. It contains two circuits working synchronously: a current pulse generator with the total capacity of 0.073 F (with a power of ~ 0.9 MJ at 5 kV) and a voltage pulse generator with an operating voltage 40 kV (with the power equal to 0.32 MJ at 40 kV). There is also a complex of control and measuring equipment which allows one to register current through the circuit-breaker being tested, measure arc voltage when the circuit-breaker contacts are opened and determine the form of the transient recovery voltage curve. The research carried out has allowed constructing a vacuum arc interrupter with a rated voltage of 10 kV, a rated current of 3,150 A, a rated short-circuit breaking current of 40 kA and a vacuum circuit breaker VVE-(S)M-10-40/3150 on its basis. We have also constructed a small-sized vacuum arc interrupter with an operating voltage of 10 kV, a rated current of 1000 A, a rated short-circuit breaking current of 20 kA and on its basis a small-sized vacuum circuit-breaker of the VBSK-10-20/1000 kind weighing 36 kg.

1. Introduction

Construction of new vacuum circuit-breakers and vacuum arc interrupters requires research into their switching ability at the earliest stages of their development. Full-scale tests of their switching elements at the development stage are impossible for reasons of economy. Therefore, research and tests at this stage are carried out in laboratory conditions and, as a rule, on synthetic test circuits. It is easy to get the identical conditions in the parameters corresponding to real operation and test conditions using a method of imposing current [1, 2]. We have built a stand for carrying out synthetic tests of vacuum circuit-breakers.

2. Description of the Stand

The basic parameters of the constructed stand of synthetic tests are given in the table.

The basic electric circuit of the synthetic test stand is shown in Fig. 1.

The stand consists of two oscillatory circuits: a circuit of power frequency current (a pulse current generator block (PCG) including a capacitor storage C1, reactors LR1, LR2 and a circuit-breaker being tested) and a circuit of transient recovery voltage (TRV) including a high-voltage pulse generator (HVPG) C3, a reactor LR3, an RC-circuit of TRV formation and a spark gap FV. The discharge PCG circuit contains a circuit-breaker for a closing device QF3, a circuit-breaker for a protective device QF4 and that for a tested device QF5.

Table. The basic characteristics of the synthetic test circuit

Mode of operation	Single-phase
Working voltage of a current circuit of power frequency, kV	5, no more
Maximum peak current, kA	100
Amplitude of TRV*, kV	21, not less
Frequency of TRV, kHz	7–8
Power consumption, kW	50, no more
* Transient recovery voltage	

The capacitor storage C1 is assembled from 396 condensers of the following types connected in parallel: IK-5-200 (154 pieces), IK-6-150 (120 pieces), IS-5-200 (122 pieces). The battery nominal capacity is 0.0732 F. The LR1 and LR2 reactors are a group of eight current-limiting dry reactors of the RB-10-400-0.35 type which can be connected in parallel-series to control the opened current period in the discharge PCG circuit. The inductance of each separate reactor is 0.18 mH.

As closing (QF3) and protective (QF4) devices we used three-phase vacuum circuit-breakers such as VVE-10-20/1600 produced by “ELKO” (town of Minusinsk) with the following parameters: the rated voltage of 10 kV, maximal breakover current of 51 kA (an amplitude value), the rated short-circuit breaking current of 20 kA (effective value). For the circuit breakers to work efficiently in the stand at a current up to 100 kA, we split the PCG discharge current to two parallel poles of QF3 and QF4 by means of the LR1 and LR2 reactors, which has allowed us to double the breaking and breakover ability of the devices. The operating life of the QF4 protective device determined by wear of the face contacts of the vacuum arc interrupters (~ 4 mm) was more than 2,000 switching-off times at a short-circuit current of 30–56 kA (amplitude value). It was achieved due to the minimal time of burning of a switching-off arc on the chamber contacts (no more than 2.5–2.0 ms) caused by the fixed phase of the moment the contacts are opened relative to zero of a short-circuit current.

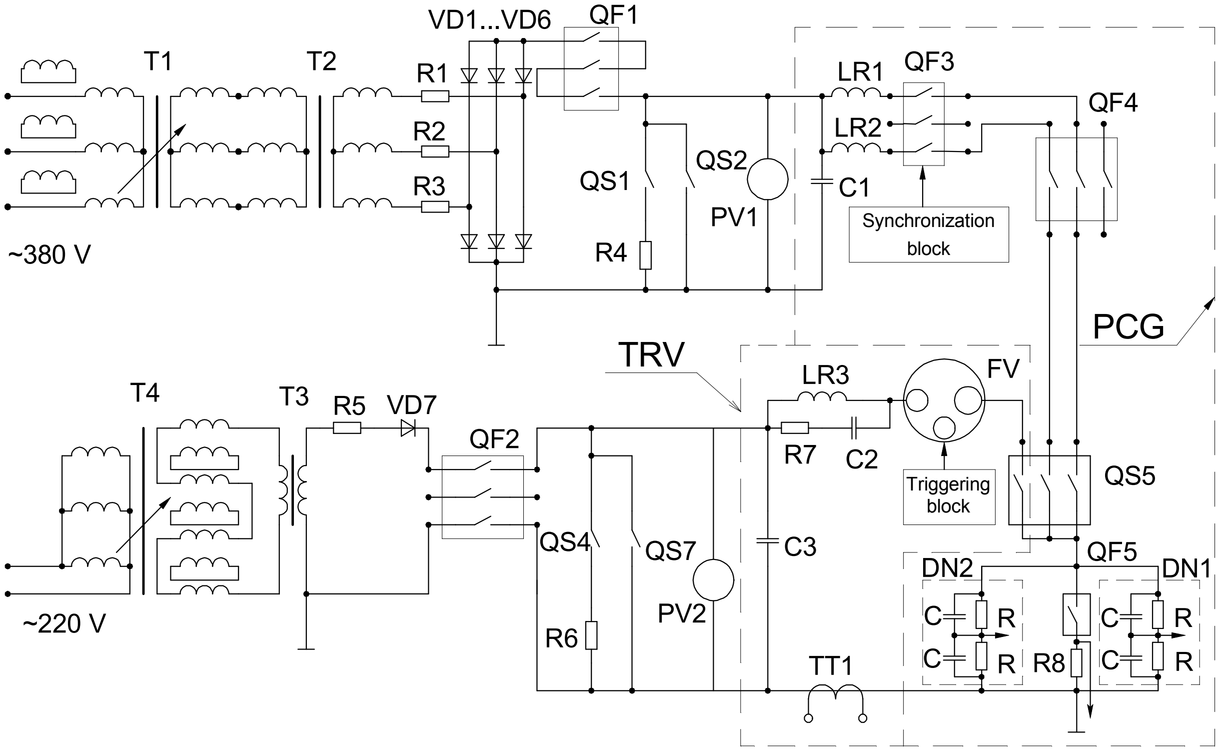

Fig. 1. The basic electrical circuit of the synthetic tests circuit. T1, T4 are the variable transformers; T2, T3 are the high-voltage transformers; R1, R2, R3, R5 are the protective resistors; VD1–VD6 are the bridge rectifiers; VD7 is the charge rectifier; QF1, QF2 are the charge circuit-breakers; C1, C3 are the capacitor storages; LR1, LR2, LR3 are the reactors; QF3 is the circuit-breaker for closing; QF4 is the circuit-breaker for protection; QF5 is the tested circuit-breaker; FV is the controllable spark gap; C2, R7 are the transient recovery voltage circuits; QS1 – QS5 are the disconnectors; R4, R6 are the resistors for dissipation of residual energy; PV1, PV2 are the kilovoltmeters; R8 is the measuring shunt; TT1 is the currents transformer; DN1, DN2 are the dividers of voltage

The condenser battery C3 consists of 40 condensers of the IK-5-40 type connected in parallel. Its total capacity is 200 µF. The LR3 reactor includes three current-limiting dry reactors of the RB-10-400-0.35 kind having taps for connection to the reactor intermediate coils. The reactor inductance is formed by means of combining connections of a various number of reactor coils to form the equality of the discharge current derivatives in the PCG and TRV blocks. The FV spark gap is an air controlled trigatron spark gap with graphite electrodes.

The stand works in the following way. When the PCG is switched on with circuit-breakers QF3 and QF4 there occurs a pulse current with a frequency close to that of power (50 Hz). The current passing through the tested circuit-breaker is shown in Fig. 2.

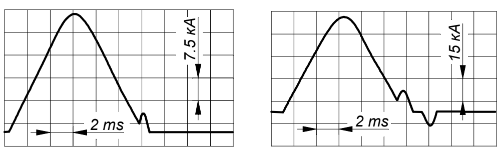

Fig. 2. Oscillograms off the current passing through the QF5 circuit-breaker being tested (on the left – successful breaking, on the right – unsuccessful one)

At the moment close to the current passing zero the FV spark gap operates and the TRV circuit is connected to the QF5 circuit-breaker being tested. The TRV circuit produces additional current through the tested circuit-breaker, the total current in QF5 is equal to the sum of the PCG and TRV circuit currents, with the current in the protective circuit-breaker remaining equal to that of the PCG circuit. As soon as the current through the protective QF4 circuit-breaker becomes equal to zero, its arc goes out. From this time a current flows through the tested circuit-breaker which is caused by the TRV circuit parameters. After the arc goes out in the circuit-breaker being tested, the transient recovery voltage on its opened contacts is determined by the TRV circuit parameters C2, R7, LR3 and the charge voltage of the C3 condenser battery. As it is seen from the oscillograms of the current passing through the tested QF5 circuit-breaker (Fig. 2), after the TRV circuit is connected the current does not look like a sine curve with a frequency of 50 Hz. However, varying the TRV circuit parameters (inductance and charge voltage) one can change the rate of current approaching to zero *di/dt*, the rate of current rise and the TRV amplitude. It allows investigating the short-circuit breaking capacity of vacuum arc interrupters in a wide range of broken currents and values of parameters of the transient recovery voltage on the contacts after the current passes zero. It also allows testing the ability of circuit-breakers to break according to the requirements of the working standard [3].

3. Results

The installation was used in the development of a new generation of vacuum arc interrupters and vacuum circuit-breakers based on them with an operating voltage of 10 kV and rated short-circuit currents of 20, 31.5 and 40 kA.

Shown in Fig. 3 (top beam) are oscillograms of the voltage applied to the switch contacts after switching off the current (TRV) and the current switched off (bottom beam) at the moment it passes zero.

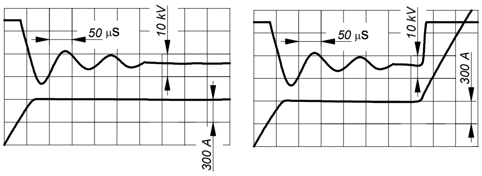

Fig. 3. The TRV oscillogram (top beam) and the breaking current oscillogram (bottom beam) (on the left – successful breaking, on the right –unsuccessful breaking)

The TRV parameters correspond to the standard requirements [3]. The vacuum arc voltage is non-stationary, therefore, the curve shape of the arc voltage between the contacts of the vacuum arc interrupter is not repeated in different experiments. Typical oscillograms of the arc voltage between the contacts of the vacuum arc interrupter at switching off are shown in Fig. 4. One can determine by the above oscillogram the vacuum arc shape (diffusion or contraction), as well as estimate the thermal energy developed on the interrupter contacts.

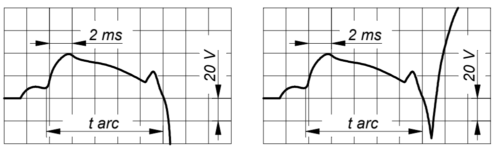

Fig. 4. The voltage oscillograms of the contacts of the interrupter (on the left – successful breaking; on the right – unsuccessful breaking)

Investigating the character of the vacuum arc for various configurations of the contact units has allowed us to develop and optimize in size hew constructions of vacuum arc interrupters, in which an arc exists in the diffusion form all through its burning when the current is switched off. We have developed an interrupter of the KDVX-10-40/3150 type with a rated short-circuit breaking current of 40 kA and a rated current of 3150 A. A construction schematic of the interrupter is shown in Fig. 5.

Besides, we have also developed a small-sized interrupter [4], which at the same value of the short-circuit breaking current has contacts with a diameter ~ 1.5 times less than the production-type vacuum arc interrupter of the breaking current of 20 kA [5], with its weight reduced 2 times.

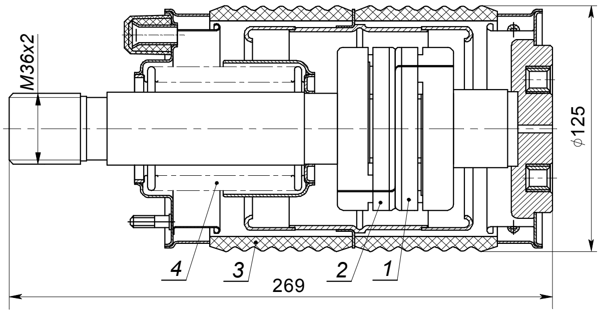

Fig. 5. A construction schematic of the vacuum arc interrupter of the KDVX4-10-40/3150 type

The tests and research carried out on the above installation have allowed developing at the earliest possible date such vacuum circuit-breakers as VBSK-10-20/1000 [4], VVE-10-31.5/1600 and VVE-10-40/3150 [6],which have successfully passed certification tests at the certification centers in Moscow and are now stock-produced by the "ELKO" company.

Conclusions

1. We have developed, manufactured and used at a research stage a stand of synthetic tests imitating full-scale operating conditions of vacuum arc interrupters and vacuum circuit-breakers with a rated voltage of 6–10 kV and a rated breaking current up to 40 kA.

2. We have carried out research into vacuum arc processes on the contacts of the new construction, which have allowed developing interrupters of the KDVX5-10-20/1000, KDVX4-10-40/3150 type. On the basis of the above interrupters we have developed vacuum circuit-breakers of the VBSK-10-20/1000, VVE-10-31.5/1600 and VVE-10-40/3150 type, which in their technical parameters are at the construction level of such advanced companies as "Siemens", for example.

References

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