TEST EXPERIENCES WITH NEW MEDIUM-VOLTAGE TRV REQUIREMENTS IN IEC 62271-100

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ABSTRACT

New transient recovery voltage (TRV) requirements have been formulated in the standard IEC 62271-100. Test experiences are reported, using the example of an epoxy resin insulated switchgear system, tested in accordance with the new transformer-limited fault TRV requirements. Also, problems and solutions are highlighted related to the testing under short-line fault TRV conditions.
In addition, the importance is emphasized of choosing a proper TRV testcircuit, in relation to the way high-frequency re-ignition current interruption influences the test result.

INTRODUCTION

In Amendment 2 of the circuit breakers standard IEC 62271-100, now fully incorporated into the consolidated edition [1], new requirements are given covering very high transient recovery voltage (TRV) stresses for circuit breakers with rated voltage below 100 kV. These stresses are associated with faults in line systems and with transformer-limited faults.
IEC now makes the following distinction between circuit breakers:

1. to be used in cable systems (class S1). There is an increase of TRV peak values (amplitude factor) for tests with 30 and 10% of rated short-circuit breaking current with respect to the previous edition 1.0 of IEC 62271-100. Also, the time-to-TRV peak (t3) is reduced for breakers having rated voltages used in North-America.
2. to be used in line systems with direct (almost no cable) connection to overhead lines (class S2). IEC chose TRV parameters as defined in the US standard ANSI/IEEE C37.06 for outdoor circuit breakers.
   In addition, also taken from the ANSI/IEEE standard, IEC now defines short-line fault TRV's for such breakers (for rated voltages ≥ 15 kV) with 75% of the rated short-circuit breaking current. A characteristic of such a fault is the very steep rising TRV due to traveling waves on the faulted overhead line (for a breaker having a rated short circuit current of 40 kA @ 50 Hz, another 20% steeper than the transformer-limited fault TRV).
3. to be connected to a transformer by a small capacitance (eg. cable shorter than 20 m; criteria are stated in normative Annex M to [1]), in order to cover transformer-fed and transformer secondary faults [2]. These faults are characterized by a TRV of very high frequency at limited fault current (typically 30% of the rated short-circuit breaking current).

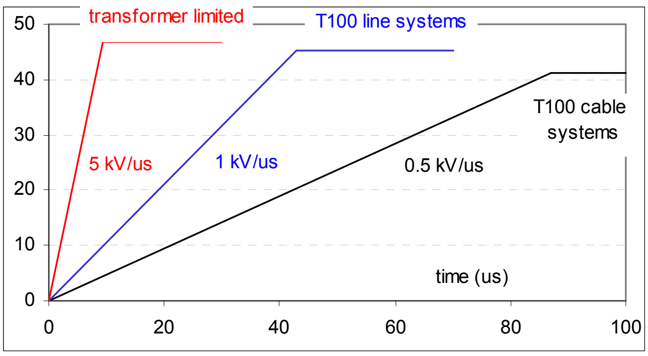

Fig. 1: IEC TRV envelopes (with rate of rise indicated) for several faults (for 24 kV rated voltage). Vertical: voltage (kV)

The main changes to the TRV requirements in [1] (apart from the mandatory short-line-fault test to be discussed further on) are higher peak values and higher frequencies.
In fig. 1, as an illustration, various IEC envelopes for a breaker of 24 kV rated voltage are indicated.

TESTING ISSUES

The reduced-current terminal fault duties with the highest frequencies – like T10 and T30 - also have the highest amplitude factors, requiring very high quality reactors of the test-laboratories to reach the required TRV peak. Also, these duties with their high frequencies and high inductivity reactors are very sensitive to stray capacitances of the connections from the TRV circuit to the test object. If these capacitances become too large – 1 nF may already be too high - the required time to the TRV peak cannot be realized. These aspects cause considerable difficulties for large laboratories where TRV- and load circuits are often situated in separate buildings, implying relatively spacious connections with high stray capacitances.

IEC permits deviations from the time-to-peak (t3) values (with 10% and 30% rated breaking current tests) if these can not be met due to the laboratory limitations. This implies that users of switchgear must pay attention to what t3 values the switchgear is tested and what t3 values it will encounter in practice. This way-out does not apply to the transformer-limited fault duty of table M1 in annex M with their extremely small time-to-peak values.

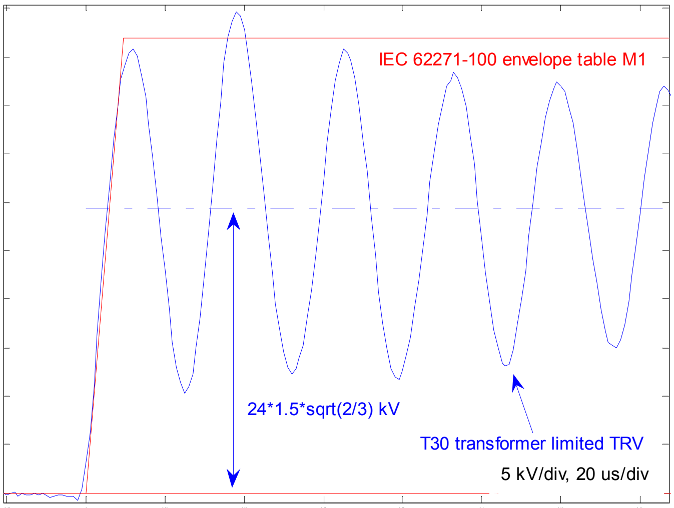

Fig. 2: Realized transformer-limited fault TRV for 24 kV testing

KEMA has successfully performed several types of tests according to this new standard with the prescribed t3 and enhanced TRV peak values; for cable, line and transformer connected circuit breakers by appropriate selection of the test-circuit layout.
In fig. 2, a transformer-limited TRV is shown, as realized for the testing of a 24 kV epoxy-resin isolated system SVS of Eaton Holec.

Short-line fault testing for medium voltage

A correct realization of a short-line-fault (SLF) test is not easy for a test laboratory, especially for MV SLF-tests with their extremely high TRV frequencies up to 1 MHz (see fig. 3). The circuitry, simulating the short stretch of overhead line (artificial line) must be placed as close as possible to the test object. This is in order to minimize stray inductances that lead to initial TRVs making the SLF test more difficult for the breaker. Also, from the stray capacitance point of view, the design of the artificial line and its placement are crucial to satisfy the conditions for correct line frequency and time delay, the latter required to be smaller than 100 ns.

Fig. 3: KEMA circuit for high-frequency short-line fault TRV for medium voltage

From measurement point of view, the frequencies involved in such SLF tests are well beyond the usual values in test-labs. Therefore, investments were needed in special voltage dividers as well as in transient recorders. KEMA has designed and successfully employed a new artificial line for MV SLF-tests as well as the measuring equipment (see fig.3).

Short-line fault testing has been emerging down from the high-voltage SF6 area into the medium voltage range, that is presently dominated by vacuum technology. In the current interruption process in SF6, the short-line fault test is well accepted already since decades because of the probability of thermal re-ignition, caused by too slow drain of thermal energy out of the gap containing the arc residue.
Since the (thermal) recovery processes in vacuum differ completely from those in gas-arc based interruption devices, it is not sure to what extent vacuum is also sensitive to short -line fault type TRVs.

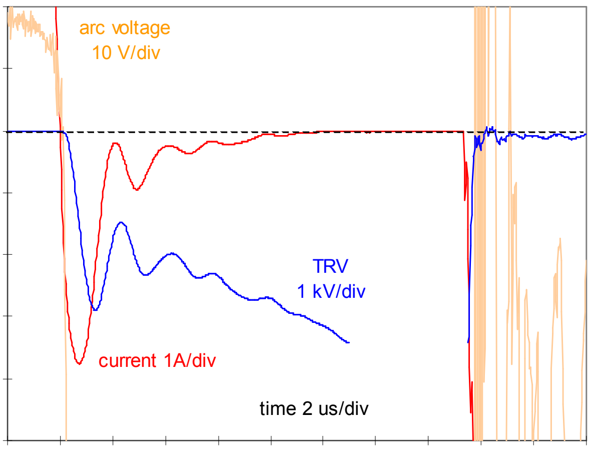

Fig. 4: Re-ignition of vacuum breakers in L90 short-line fault test-duty 16 us after interruption and 5 us after decay of post-arc current

Detailed measurements in the critical interruption region of current zero [3] in vacuum of KEMA on a limited number of vacuum interrupters suggest that the dominant re-ignition mechanism takes place outside of the thermal area (roughly defined as the few microsecond duration of the post-arc current), or outside the rising edge of the short-line TRV component. A typical example is the current zero measurement of fig. 4.

In order to avoid over-testing, further systematic research is necessary on the probability of thermal re-ignition in vacuum in addition to accumulation and evaluation of experience with short-line fault testing of both SF6- and vacuum switchgear.

TESTED EQUIPMENT

General system description

The SVS system of Eaton Holec is a metal enclosed, single busbar switchgear system with fixed built-in vacuum interrupters. The system is fully single pole insulated by epoxy resin, see fig. 5. All connections between the primary components have rubber sleeves. In this way a constant safe insulation level is maintained throughout the switchgear and the insulation embedded primary parts are categorised 'compartments' according to IEC 62271-200 (formerly IEC 60298).

The earthed metal enclosure guarantees an extra physical safety during normal operation.

The cable feeder units may contain a load-break switch, a fused load-break switch or a circuit-breaker, where all main switching functions are performed by a vacuum interrupter.

SVS is of a modular construction. This enables any combination and sequence of panels, including measuring panels and direct busbar connections. There is no restriction to the number of panels to be coupled, and extension at site is possible.

SVS has been developed for application in transformer stations and nodal points in medium voltage distribution networks and as medium voltage connection to industrial sites and building complexes.

The SVS08, as the most commonly used system within the family, is designed according to IEC with rated voltage up to and including 24 kV, where the design for the lower nominal voltages are practically identical to that of 24 kV. Rated currents are up to and including 630 A (busbar 800 or 1250 A) with rated short circuit currents up to 20 kA.

The SVS 12 system may also consist of circuit-breaker panels for 1250A, 25 kA.

Project to increase the specifications

To rationalize the production of the SVS, a project was realized to introduce a single design of vacuum interrupter for both 12 and 24 kV specifications, where up to now two types were needed (≤ 17.5 kV - 20 kA and 24 kV -16 kA) for the circuit breaker function.

Thereupon the marketing wish was there, to increase the specifications to 24 kV - 20 kA - 3s. This was the leading theme for the project. Of course the applicable vacuum interrupter (VB20, Eaton made) to build the circuit-breaker NVS20, had to be integrated in the mould by the Eaton Holec direct casting technology, as used on SVS since the first day.

This SVS project was just about to finish when the new

Fig.5: SVS08 panel

Amendment 2 on IEC 62271-100 (circuit breakers) came out in July 2006. So the ideal moment was there to re-certify according to the new IEC demands in the KEMA laboratories.

The certification tests

The ratings of the circuit-breaker NVS20 in SVS were 24 kV – 630 A – 20 kA / 50 kA peak with a short time withstand current of 20 kArms during 3 s. Rated operating sequence O – 3min – CO – 3min – CO, suitable for all networks both solidly and non solidly earthed neutral.

The following tests were all performed according to IEC 62271-100 on one and the same panel SVS, equipped with the NVS20 circuit-breaker:

The short time withstand current test and peak withstand current test, the short circuit test duties T10, T30, T60, T100s and T100a, the double earth fault (DEF) and single earth fault test (SP), the short line fault test (L75), plus cable charging current tests (CC1 and CC2), out of phase making and braking tests (OP2) and T30 for transformer-limited faults (TLF).

The NVS20 circuit breaker in SVS passed all tests on a single panel, where the IEC standard allows for several new breakers for the various tests. Not a single NSDD or restrike occurred during the complete test regime. Apart from the E2, C2, the newly introduced classification S2 is also

demonstrated.
Also demonstrated during the KEMA testing was the 20 kA - 3s short time withstand current for the SVS system itself.

CHOICE OF TRV CIRCUIT

In circuits for short-circuit current interruption tests, the wave shape for the transient recovery voltage (TRV) prescribed in the standards can in principal be produced either with a series damped or with a parallel damped circuit, see fig. 6. The principal difference between the two is the rate of rise of voltage immediately after interruption. In test-laboratories, the parallel damped circuit must be realized with lumped elements, the capacitance of which is located close to the test-breakers, in order to prevent any unwanted initial rise of the TRV. For the parallel damped circuit, the resistor bank dissipates a considerable amount of energy. A hybrid solution is a series damped circuit with a (delay) capacitance in parallel, resulting in a zero initial rate of rise.
At a breakdown of the interrupter-gap shortly after interruption (usually termed re-ignition), the resulting HF current (starting at t = 0 in the lower section of fig. 6) will initially be supplied by the TRV circuit, causing a different waveshape depending on what circuit is used.
In the parallel damped circuit, a high-frequency oscillating

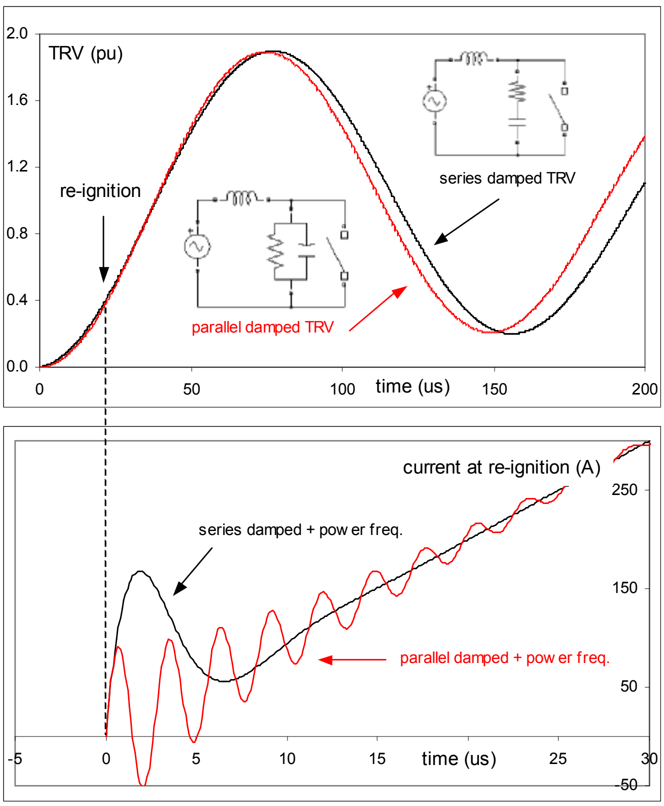

Fig.6: Comparison of series-and parallel damped TRV circuit and re-ignition current (time scales are different).

current will flow, that may be interrupted by the (vacuum) breaker, causing a successful interruption. In the series damped case, the re-ignition current can be overcritically damped having a wave shape without zero crossings. In this situation, the power frequency current will re-establish and the interruption fails. This principal difference is outlined in fig. 6, lower part.
Therefore, the choice of the TRV circuit topology, has consequences for the interruption process, though the (inherent) TRV waveshape matches the standards.
It is KEMA's practice to use the parallel damped circuit for testing, since field tests with discharging lines and cables have shown an oscillatory reignition current to be the realistic choice [4].

SUMMARY AND CONCLUSIONS

Additional test requirements have now been formulated in the IEC circuit breaker standard for distribution circuit breakers directly connected to overhead lines or having to interrupt transformer-limited faults.
These breakers have to be tested with a higher rate-of-rise of transient recovery voltage than in the past. This will cause additional efforts by test laboratories, that have to provide circuits able to produce (much) higher frequencies of transient recovery voltages than in the past.
Also, measurement equipment must be adapted for this.
It is demonstrated that KEMA can now cover these new test requirements.
The transformer-limited fault test-duty was demonstrated with a vacuum breaker of a metal-enclosed epoxy-resin insulated switchgear system from Eaton Holec. Performance of test-object and test-circuits were both excellent.
Also medium-voltage short-line fault tests-circuits and measurement instrumentation have been developed.
The topology of test TRV-circuits is important in case the tested breaker can interrupt high-frequency re-ignition current, such as vacuum breakers.

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