TEST EXPERIENCES WITH A NEW GENERATOR CIRCUIT BREAKER BASED ON VACUUM TECHNOLOGY

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ABSTRACT

This contribution highlights the testing of generator circuit breakers, in particular the testing of a 17.5 kV vacuum generator circuit breaker that was type-tested up to 72 kA in a direct circuit. Differences in the requirements of generator circuit breakers with general purpose breakers are highlighted.

INTRODUCTION

Generator circuit breakers have to fulfil a number a special requirements that differ greatly from "general purpose" circuit breakers. Apart from the very high nominal current carrying capacity, the faults that have to be dealt with by generator breakers have a peculiar nature. In the system source fault (fault between generator breaker and generator), very steep transformer-dominated transient recovery voltages (TRV) are produced, whereas generator source faults (faults between generator breaker and transformer) can result in missing current zeroes that prolong the arcing time. In addition, the out-of-phase requirements are very severe.

This contribution focusses on a new development in this respect: the application of a vacuum circuit breaker as generator breaker.

Testing has been performed with this device, as yet in a direct circuit, in which currents and (transient) voltages are produced by a single source. In a further stage of development, it is necessary to use a synthetic circuit, in which an auxiliary circuit is used to produce the special values of the TRV.

STANDARDISATION STATUS

In IEEE Std. C37-013 [1] relevant test-requirements are laid down for generator circuit breakers, intended for generators ranging from 100 - 1000 MVA. Recently (Nov. 2006) draft Amendment 1: Supplement for use with Generators 10 - 100 MVA was released [2]. The main topic of this draft is to include TRV requirements in the generator power range 10 - 100 MVA and to provide guidance on how cables between transformer and breaker can affect TRV.

In IEC, a separate generator breaker standard does not exist and the IEC 62271-100 circuit breaker standard excludes generator breakers. However, practice is often to employ "general purpose" breakers (type tested per IEC 62271-100) in a range 20 - 50 MVA as generator breakers. The authors wish to make clear that certain requirements will not automatically be covered in this case, and case study is necessary.

To illustrate this, several TRV waveshapes of generator breaker duties (intended for a 15 kV generator rated 200 MVA) are combined in fig. 1, and compared to the T30 TRV of a general purpose breaker with a rated voltage of 15 kV. As can be seen, rate-of-rise and peak value of TRV of the generator breaker system source - and out-of-phase fault duty are far higher than for general purpose breakers, even those qualified for line systems (S2 class), as defined recently in IEC 62271-100 ed. 1.2 (2006). In addition, in contrast to general purpose breakers, generator breakers have to deal with very steep TRV following very high current, whereas normally for general purpose breakers the steepest TRVs result following moderate to low current interruption.

In applications with lower power, the step-up transformer is often connected with a cable to the generator breaker (in stead of a bus). In this case, the peak value of the system source fault TRV increases, whereas the TRV rate-of-rise decreases. From the examples of IEEE PC37.013a/D6 [2], proposed to be included as Annex B in a future version of the IEEE generator standard [1], it follows that only considerable length of cable (> 20 m) combined with small MVA generator ratings (< 20 MVA) can be effective to reduce TRV rate-of-rise strongly, but still at the cost of increase of the TRV peak value [3].

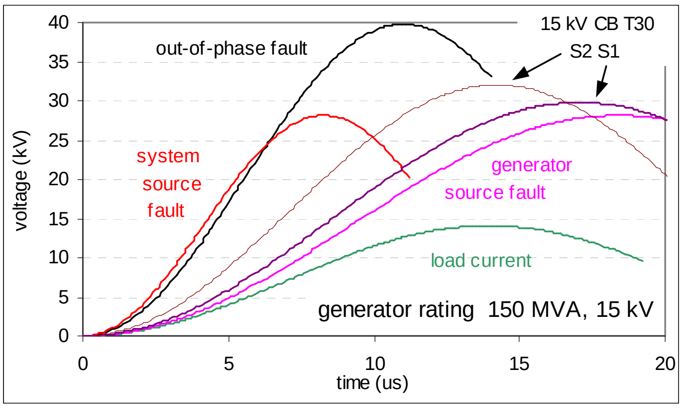

Fig. 1: TRV shapes of some generator circuit breaker (rated 15 kV, 200 MVA) duties compared to general purpose 15 kV circuit breaker T30 TRV (S1 intended for cable systems, S2 for line systems)

In fig. 2, TRV rate-of-rise of generator breaker fault interruption duties are compared to the TRVs belonging to the maximum fault current (T100 duty) of a general purpose 15 kV breaker. From this, it becomes clear that a breaker, type tested in accordance with IEC 62271-100, even with very high rated breaking current, e.g. 63 kA, generally falls short to fulfil the very severe generator TRV requirements**.**

TESTING

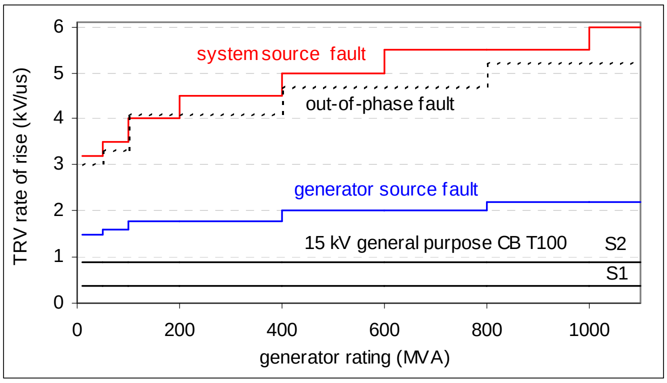

Fig. 2 :Rate of rise of TRV of generator circuit breaker duties [2] as a function of generator rating compared to general purpose 15 kV circuit breaker T100 (maximum current) TRV (S1 intended for cable systems, S2 for line systems)

High-power testing of generator circuit breakers sets extreme demands to test laboratories. It is the combination of high current and steeply rising TRV that is generally a challenging combination to test-engineers. KEMA has the following solutions for generator breaker testing:

Direct three-phase testing

This is a method guaranteeing the highest degree of equivalence to the service situation, and can generally be applied up to 100 kA at nominal output voltage of the generators (15 – 17 kV, depending on the power frequency). In a typical three-phase direct circuit, the output of the generators is directly fed into the test-bay (without transformer) through a 17 kV busbar system designed for 400 kA_{RMS}. The testing described in this contribution was performed in this manner.

Direct single-phase testing

In this method, the output voltage of the short-circuit generators is transformed to the desired voltage level. Having a total available power of 4800 MVA single phase (8400 MVA three-phase), KEMA's test facility is able to supply current up to 120 kA_{RMS} at a voltage level of 31 kV. TRV requirements are met through suitable networks.

Synthetic three-phase testing

This method is used for testing the larger SF6 units typically 25 kV with 100 – 120 kA (for generators in the order of 1000 MVA). In this case KEMA's synthetic installation is added to the high-current circuit. Hereby, the appropriate values of TRV can be produced using the current injection method. KEMA's synthetic installation is a double LC circuit (energy 2*1.7 MJ), designed for three-phase synthetic testing. In these tests, only one LC circuit is used to produce the injection current, in separate tests on the first and last poles to clear respectively. The other LC unit is needed for arc prolongation. A new method for arc prolongation is developed that can produce far higher current than the arc prolongation circuits normally used in high-voltage synthetic testing. Such a circuit is necessary to produce a realistic arc duration in synthetic tests.

The auxiliary breaker for isolation of the current source from the HV-source, must also be a generator circuit breaker of similar rating as the tested one.

Experience with this circuit is up 120 kA at 25.3 kV [4]

Single-phase synthetic testing

This method is applied for the most powerful units (up to 2000 MVA). The main problem is in the magnitude of current involved (up to 210 kA_{RMS}, 600 kA_{pk}). This requires accurate control of the extreme forces on the conductors supplying the main current. Specially designed heavy buswork is in use, yet allowing a certain degree of flexibility. This is connected to the main 400 kA busbar system of the laboratory which is directly connected to the current source: four generators in parallel.

The second problem is in the very steep values of TRV which can not be reached with the standard MV TRV circuitry that is located some tens of metres from the test-object. Also here, a synthetic circuit is employed, triggered with a special making device, allowing triggering at relatively low voltage (order of 35 kV).

Experience with this circuit is up to 210 kA at 25.3 kV [5].

For general purpose circuit breakers, IEC 62271-100 requires a power frequency recovery voltage during a period of at least 300 ms from interruption. Synthetic circuits by their nature do not produce these ac recovery voltages, so special circuits must be developed. For the case a breaker has to be type tested according to IEC 62271-100 and IEEE Std. C37.013 (breaker can then double as generator- and high-current general purpose breaker), KEMA has synthetic circuits available that produce transient recovery - as well as power frequency recovery voltage in a single circuit.

VACUUM GENERATOR CIRCUIT BREAKER

General

By its specific features, vacuum as an interrupting medium behaves differently from SF6 or compressed air, that are usually employed in generator breakers. Thanks to its well-known excellent dielectric recovery, vacuum is by nature better suited than gasses to cope with the fast rising TRV involved in the generator breaking application.

The challenges of the designer of vacuum generator breaker then are located in the following areas :

1. Due its 'straightforward 'butt-type' contacts, very high nominal current carrying capacity of vacuum breakers can only be achieved with very high contact force;

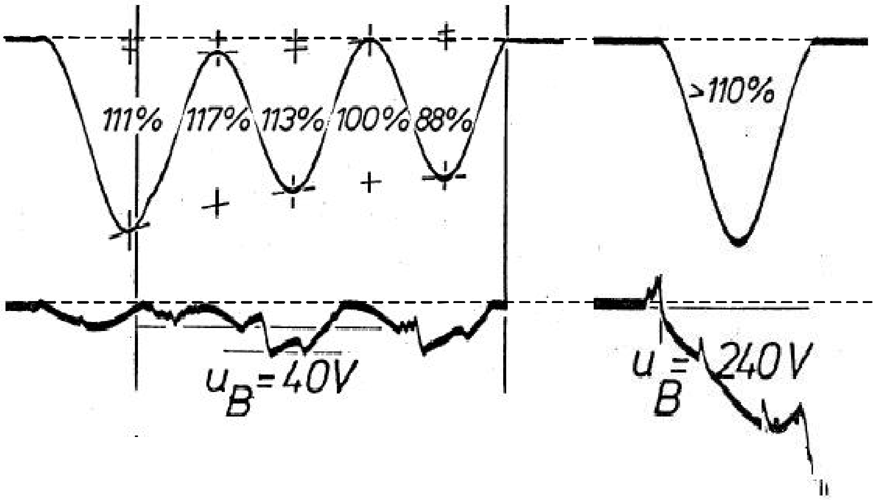

Fig. 3: Oscillograms of 10 kA tests by Siemens (early-eighties of last century) regarding missing current zero with vacuum breaker (left) and oil circuit breaker (right). Upper trace: current, lower trace: arc voltage.

2. Long arcing times and high asymmetry such as occur in the generator-source faults need a very careful design of (radial magnetical field) arc control;
3. The arc voltage of vacuum breakers is much lower than of gasfilled breakers. The advantage is a lower thermal stress of the breaking chambers, the disadvantage is the impossibility to interact with the circuit in order to advance current zero in the case of very high asymmetry during a generator source fault. This is illustrated in fig. 3 of early tests, showing that the relatively high arc voltage of a minimum oil circuit breaker can "advance" current zero, whereas "vacuum" has to wait for current zero because of its low arc voltage.

Circuit breaker parameters

History of Siemens development

The development started with the application of general purpose circuit breakers for extreme service situations such as occur for example in the off-shore industry. In such applications, short-circuit currents arise that have an asymmetry that far exceeds the values, obtained with test-circuits having 45 ms dc time constant, as the IEC 56 and its successors prescribed. Already early in the development of vacuum breakers, Siemens investigated the limits of interruption of vacuum technology, such as for example occur with short-circuit currents having an asymmetry higher than 75%. Around 1980, comparative tests were performed at 10 kA level between minimum oil breakers and vacuum breakers with respect to their behaviour towards missing current zero (see fig. 3). This leads to unusually large, but controllable arcing times. With the 3AH38 breaker, an arcing time of 50 ms (at a level of 31.5 kA) was demonstrated.

The final breakthrough of the vacuum generator circuit breaker came in the 90s with rated short-circuit breaking current of 50 kA at 15 kV rated voltage in cooperation with ENEL. This was demonstrated with tests in both direct and synthetic test circuits.

Actual status

The modular high-current and generator vacuum circuit breakers 3AH37 /3AH38 from Siemens was type tested up to 72 kA in accordance with IEEE Std. C37-013. The breaker has rated voltage of 17.5 kV and is available for nominal current up to 6300 A and short-circuit current up to 72 kA.

During the design work, simulations in mechanics, electrical and thermal fields were necessary. The optimisation of contact material, contact system of the interrupter as well as the mechanical properties of the breaker are the basis of success. Existing subassemblies of the 3AH3 family were used.

Three-phase direct tests up to 72 kA were done in the Siemens test laboratory and at KEMA. All development testing was done at Siemens. The final type tests were done at KEMA.

The increase of rated voltage up to 24 kV will be the next step in the development. Therefore, an understanding of the plasma physics and the influence of the arc voltage on the breaking process is necessary.

Based on the results and experience in high-current and generator vacuum circuit-breakers breaking capabilities up to 100 kA in vacuum are possible.

In fig. 4, a typical oscillogram of an interruption of 80.1 kA

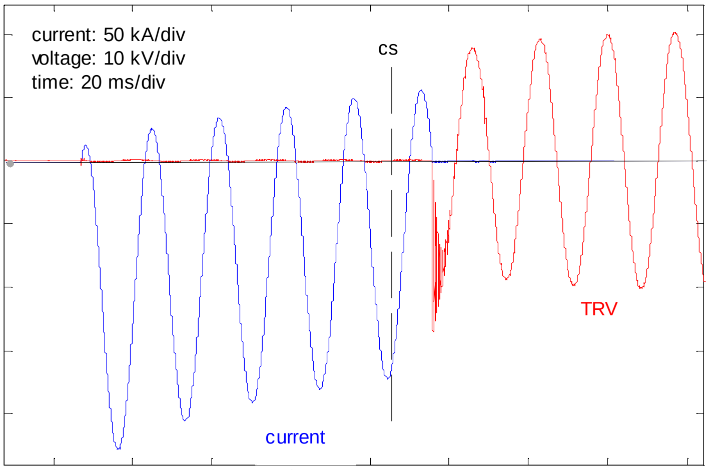

Fig.4: Interruption of 80.1 kA$_{RMS}$ current with 53% asymmetry by a vacuum genererator circuit breaker. cs: contact separation. The figure shows one phase of a direct three-phase test.

current is shown. Very high asymmetry is produced here, leading to a first asymmetrical current peak of 228 kA and asymmetry (at contact separation) of 53%.
Fig. 5 shows the object in the KEMA test-station. In fig. 6 the circuit breaker and interrupter are shown.

DISCUSSION AND CONCLUSION

Due to specific network requirements, such as a very steep rise of transient recovery voltage after fault current interruption and a very high degree of asymmetry of short-circuit current, general purpose circuit breakers are generally not suited to fulfil generator circuit breaker duties.
Therefore, special standards have been developed (the main points of which are described in this contribution) and special breakers are developed.
As a consequence, test laboratories have to develop test circuits, in order to verify the various duties required.
Because of the unusually severe requirements, also such tests demand great efforts from test laboratories, and sometimes there is no other choice than to perform partial tests, each part directed towards a specific duty.
Thorough technical knowledge and understanding of the background of standards is then required in order to allow subdivision of the stresses - combined in service - into several part-tests.
An example of this is the combination of transient recovery voltage and power frequency recovery voltage, that can in principle be realized in a single test circuit.

Fig. 5: Siemens vacuum generator circuit breaker under test at KEMA

Another example is single-phase vs. three-phase testing. In the single-phase case, great caution must be exercised in order to simulate the phase-to-phase (dynamical, mechanical) interaction when testing single phase.
A relative newcomer in the field of generator breakers is the vacuum circuit breaker. Direct three-phase tests up to 72 kA are described that confirm the performance of both test-circuit and test-object.

REFERENCES

[1] IEEE Std. C37.013-1997: "Standard for AC-High Voltage Generator Circuit Breakers Rated on a Symmetrical Current Basis", IEEE New York

[2] IEEE PC37.013a/D6, Nov. 2006, "Standard for AC High Voltage Generator Circuit Breakers Rated on a Symmetrical Current Basis - Draft Amendment 1: Supplement for use with Generators Rated 10 - 100 MVA", IEEE New York

[3] D. Dufournet, G.F. Montillet, 2002, "Transient Recovery Voltage Requirements for System-Source Fault Interruption by Small Generator Circuit Breakers", *IEEE Trans. Pow. Del.*, vol.17, no.2, 474-478.

[4] R.P.P. Smeets, W.A. van der Linden, 1998, "The Testing of SF6 Generator Circuit-Breakers", *IEEE Trans. Pow. Del.*, vol.13, no.4, pp. 1188 - 1193

[5] R.P.P. Smeets, H.D. Barts, L. Zehnder, 2006, "Extreme Stresses of Generator Circuit Breakers", *CIGRE Conference*, paper A3-306

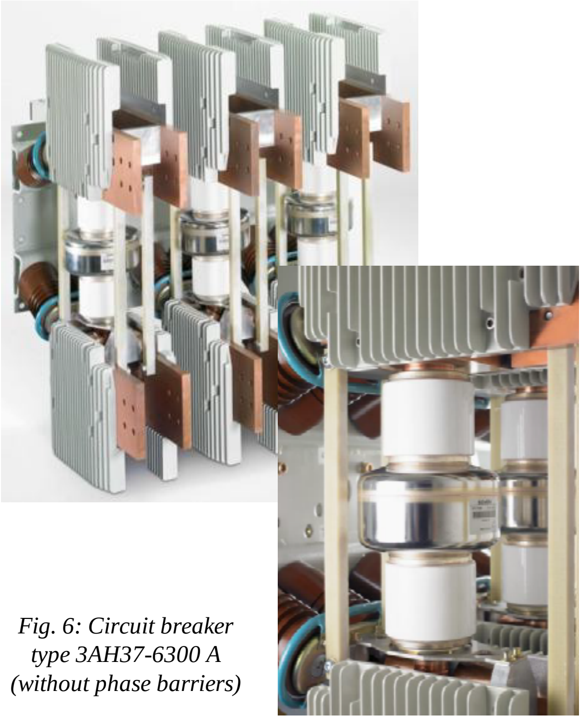

Fig. 6: Circuit breaker type 3AH37-6300 A (without phase barriers)