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Vacuum circuit-breakers and X-rays

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Blue technology
with Zero F-gases

1 Introduction

The use of our Blue circuit-breaker portfolio offers all our customers an environmentally friendly switchgear solution.
This portfolio is based on reliable and proven vacuum switchgear technology for switching electrical currents. Vacuum interrupters connected to high voltage can be emitters of X-rays, due to the physical processes involved. They are devices which produce stray radiation. Siemens-Energy's vacuum interrupters are designed and type-tested (according to International Electrotechnical Commission / American National Standards Institute, Inc.) in such a way that, under operating conditions, X-ray radiation occurs only far below the permissible limits and background radiation.
In the exceptional case of an application of test voltages to the open vacuum circuit-breakers, separate measures must be taken for personal protection.

2 Physical background

2.1 Natural background radiation

We are all exposed to natural radiation in our daily lives. Depending on where we live and our habits, our exposure ranges from 1 mSv to 10 mSv per year (e.g., cosmic and ground radiation, the ingestion and inhalation of natural radioactive substances like Radon) [1]. Assuming an average value of 3.5 mSv per year, the received dose rate of background radiation is 0.4 µSv/h. However, aside from natural sources, there are also man-made radiation sources which contribute to the overall exposure. In this context, for example, medical devices and treatments, and airplane flights must be mentioned.

Exposure to sources of stray radiation, such as cathode-ray tube televisions or vacuum interrupters, also falls into this category.

2.2 Emission of *Bremsstrahlung*

X-rays are emitted when electrons of high kinetic energy impact surfaces in a vacuum. Also, in the case of vacuum interrupters with an applied high AC voltage, electrons will escape from the metallic surface of the contacts (tunnel effect) and will be accelerated in the electric field between cathode and anode. When these electrons hit the surface of the opposite contact (anode), *Bremsstrahlung* (X-rays) will be emitted (see Figure 1). Dohnal [2] was one of the first to investigate the emission of X-rays from electrode configurations in a vacuum with applied high voltage.
Further information can be found in references [3], [4] and [5].

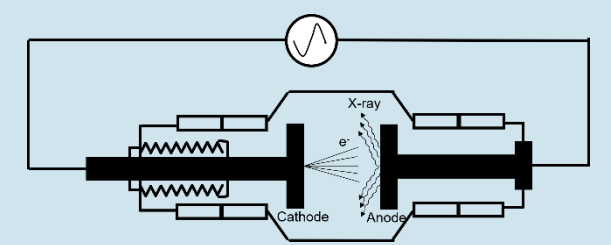

Figure 1: X-ray emission at a high-voltage vacuum interrupter in open position and with an applied high AC voltage.

Regarding the effect of X-rays above a specific exposure level and its risk for human beings please refer to [6].

3 Relevance of X-rays for vacuum interrupters

3.1 Conditions for emission

The emission of X-rays from vacuum interrupters depends on several factors. The following list reflects the key aspects:

- **Under normal operating conditions, the emission of X-rays is far below the exposure limits. Corresponding verification tests according to IEC / ANSI and for local German legislation are available.**
- Figure 2 shows a comparison of X-ray emission from a vacuum circuit breaker to natural background radiation and exposure during flights. Under normal operating conditions, the X-ray emission from vacuum interrupters is lower than the natural background radiation.
- X-ray emission higher than the exposure limit only becomes relevant when high AC voltage is applied to the open contact gap of the vacuum interrupter (i.e., U > Ur, when U is significantly higher than the rated voltage Ur of the vacuum circuit breaker).
- At a specific voltage level (higher than Ur), the X-ray emission will exceed the level of the natural background radiation. And as the voltage increases further, the emission will also increase, [3].
- In the closed position of the vacuum switchgear, X-ray emission from the vacuum interrupter is irrelevant.
- The X-ray emission related to transient recovery voltage stress after current interruption was measured and is negligible.
- The de-energized vacuum circuit-breaker is not a source of X-rays!

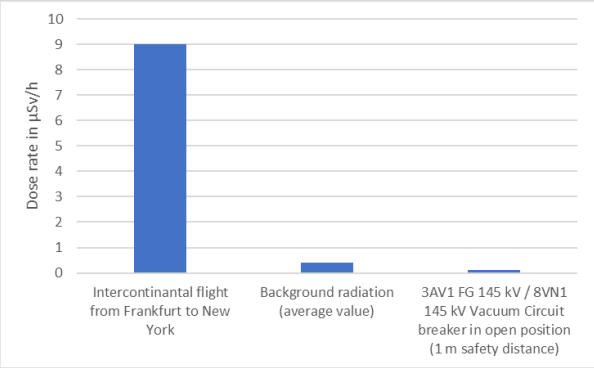

Figure 2: X -ray emission from a high-voltage vacuum circuit breaker under operating conditions in comparison to background radiation and X-ray exposure during international flights.

The above-mentioned points highlight the situations in which the emission of X-rays must be considered, and where appropriate protective measures must be taken. Figure 3 gives an overview of the relevant situations.

Operating conditions **U ≤ Ur grid operation voltage**		***Test conditions*** **U > Ur e.g., routine test voltage**	
CB closed	**CB open**	**CB closed**	**CB open**
Emission level < 1 µSv/h		**Emission level < 1 µSv/h**	**Emission level can exceed 1 µSv/h**

Figure 3: Overview of circuit-breaker (CB) conditions and related X-ray emission levels (operating conditions vs. test conditions).

All conditions directly related to the operation of circuit-breakers (U ≤ Ur) show received doses of X-rays of less than 1 µSv/h. This is a value that is generally viewed as uncritical and does not require protective measures.

Testing the vacuum circuit-breaker with high AC voltages well above the rated voltage (U>Ur), is a different situation, because emission levels higher than 1 µSv/h can occur. This is the case, for example, for type testing and routine testing of the vacuum circuit-breaker at Siemens Energy facilities.

Siemens Energy, as a manufacturer, is well aware of this and has taken appropriate protective measures for the personnel working under these test conditions.

Another situation that can possibly result as a test condition is the on-site test of the vacuum circuit-breakers.

For air-insulated systems, the function test is covered by the factory routine test and does not require any further verification at the substation.

For gas-insulated substations, the complexity of the configuration is higher and on-site tests with up to 85 % of the rated short-duration power frequency withstand voltage are performed. In general, this is done in the closed position of the circuit-breaker, i.e., there is no significant X-ray exposure near the vacuum interrupter. However, in the open position, this can be different depending on the test conditions (e.g., test voltage).

In the case that a test in open position of the vacuum circuit-breaker shall be done with U > Ur, suitable protective measures might be necessary. The type and scope of the measures depend on the individual conditions of the test (e.g., the level of the applied voltage).

3.2 Available type test documentation

Siemens Energy's vacuum circuit-breaker products are type-tested according to the relevant international standards, such as IEC and ANSI [7], [8]. This also concerns the possible emission of X-rays. Corresponding verifications are performed in accordance with these standards, thus ensuring that the devices can be operated safely.

In these tests for the emission of X-rays, a distinction is made between the operational case and the test situation. For the operating case, a clearly defined limit-value must be complied with.

For Siemens Energy products we apply even lower X-ray limits (than those required in the standards), in accordance with the German Type Approval. Up to the rated voltage U = Ur, the products must meet the limit value of 1 µSv/h at 0,1 m from the accessible surface.

If, in addition to the existing documentation, further documents or approvals are required (e.g., due to local safety standards), Siemens Energy will support the necessary activities.

3.3 Product documentation with regard to X-ray emission

The possible emission of X-rays is also addressed in the product documentation, i.e., in the operating instructions, in the routine test documentation, and in the labeling of the vacuum circuit-breaker itself.

The operating instructions for the vacuum switchgear contain general warnings about X-rays. In addition, we point out possible risks when carrying out high-voltage alternating current tests with U > Ur in the open switching position.

The routine test documentation contains vacuum interrupter-specific quality documents that document the high-quality standard of the vacuum interrupters used.

4 Conclusion and recommendations

With respect to the potential emission of X-rays, Siemens Energy's vacuum circuit-breaker products are well below the limits defined in international standards and the German type approval under all operation conditions!
Under test conditions, with test voltages much higher than the rated voltage (up to the rated short-duration power-frequency withstand voltage) and with open contacts of the vacuum circuit-breaker, X-rays can be produced which exceed the background radiation. During the short period of the test phase with vacuum circuit breakers under these conditions, appropriate protection measures must be taken. The implementation of a sufficient safety distance can be an appropriate measure.
In addition, for these test situations, local legal requirements may apply.
An appropriate measure to ensure personal X-ray protection during commissioning tests for GIS equipment is a voltage test with the vacuum circuit-breaker in the closed position.

5 Bibliography

Author: S. Giere

[1] www.bfs.de, Bundesamt für Strahlenschutz, 23.10.2023, BfS - Natural radiation in Germany - Natural radiation in Germany
Last access: 23.10.2023

[2] D. Dohnal, "Untersuchung zur Röntgenstrahlung an Hochspannungs-Hochvakuum-Anordnungen", Dissertation, TU-Braunschweig, 1981

[3] S. Giere *et al*., "X-Radiation Emission of High-Voltage Vacuum Interrupters: Dose Rate Control under Testing and Operating Conditions", 28th ISDEIV, September 23rd, 2018, Greifswald, Germany

[4] J. Yan, Z. Liu *et al*., "X-Ray Radiation of a 126 kV Vacuum Interrupter", 25th ISDEIV, 2012, Tomsk, Russia

[5] R. Renz, D. Gentsch, "Permissible X - ray radiation emitted by vacuum - interrupters / - devices at rated operating conditions" 24th ISDEIV 2010, Braunschweig, Germany, 2010, pp. 133-137

[6] www.icrp.org, ICRP, 2007. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann. ICRP 37 (2-4)., https://journals.sagepub.com/doi/pdf/10.1177/ANIB_37_2-4
Last access: 06.12.2023

[7] IEC 62271-1; High-voltage switchgear and controlgear – Part 1: Common specifications for alternating current switchgear and controlgear, Edition 2.0, 2017-07

[8] ANSI C37.85-2020; American National Standard for Switchgear – Alternating-Current High-Voltage Power Vacuum Interrupters – Safety Requirements for X-Radiation Limits; 2020-06

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