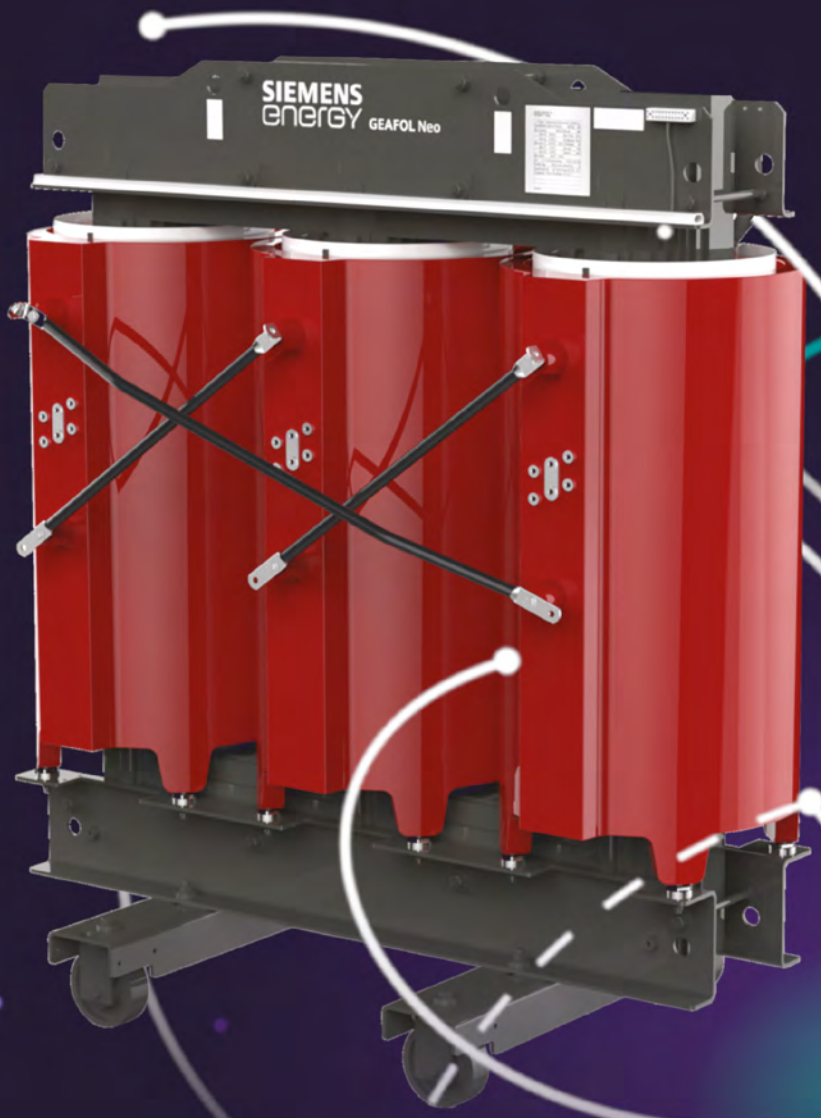


GEAFOL® cast-resin transformers – resistant to overvoltage by design

ABSTRACT

Safe, reliable, and eco-friendly: GEAFOL® cast-resin transformers from Siemens Energy have been providing a wide range of customer benefits since the product launch in 1966. The combination of cast-resin transformers and vacuum circuit breakers (VCB) has been used successfully for more than 30 years in industry and utility service. Switching tests with more than 500 switching-off operations with different configurations, carried out in the last few years, assessed the transient behaviour of vacuum circuit breakers with Siemens Energy's cast-resin transformers under real installation conditions. The results show overvoltage factors far below critical values and confirm the safe usage of vacuum circuit breakers with Siemens Energy's GEAFOL® cast-resin transformers.

KEYWORDS

dry-type transformer, vacuum circuit breaker, switching transients, GEAFOL, Siemens Energy

Unlike traditional fluid-immersed transformers, cast-resin transformers operate with high-voltage windings fully encapsulated in cast-resin insulation, which makes a tank with insulating and cooling liquid unnecessary

Extremely safe, reliable in operation and environmentally compatible – Siemens Energy cast-resin transformers provide great customer benefits

Distribution transformers are mainly used where electricity needs to be transformed from the medium voltage level down to low voltage, or to another incoming grid voltage level. Unlike traditional fluid-immersed transformers, cast-resin transformers operate with high-voltage windings fully encapsulated in cast-resin insulation, instead of transformer oil or other liquid insulating materials, which makes a tank with insulating and cooling liquid unnecessary. Thanks to this apparently simple idea, the technology has been successful since its market launch in 1966. The percentage of cast-resin transformers, compared with traditional, oil-immersed distribution transformers, continues to grow worldwide – with good reason, as they offer characteristic benefits.

To avoid long low-voltage cable routes that increase transmission losses, transformers are usually installed near the electrical loads. This almost always means in areas frequented by people, which is why transformers must operate extremely safely and reliably. This applies as much to high-rise buildings, hospitals, data centres, metro stations, ships, and oil rigs as it does to paper mills, rolling mills, airports, and other infrastructure with high power requirements. In addition, transformers often operate near passers-by and residents, only separated from their immediate surroundings by the wall of a secondary unit substation or transfer substation or by a metal housing. That's why safety is everyone's top priority.

Dry-type cast-resin transformers provide a particular degree of safety in operation, especially due to their electrical strength and excellent fire behaviour – they are flame resistant and self-extinguishing. At the same time these transformers are eco-friendly and virtually completely recyclable, which makes them the perfect choice for areas where environmental protection is required. There are practically no restrictions on the place of installation of cast-resin transformers.

Siemens Energy cast-resin transformers are virtually maintenance-free and their high overload capacity ensures maximum reliability. Given appropriately high-quality standards in development, design, engineering, and production, GEAFOL transformers are reliable in operation, environmentally compatible, flame-retardant, self-extinguishing, and non-toxic.

Siemens Energy has the necessary experience, having already installed more than 150,000 GEAFOL cast-resin transformers worldwide

The quality of the transformers is constantly monitored by OEM-independent international testing institutes. As part of an extensive program of numerous complex tests, the GEAFOL transformers are evaluated for vibration resistance, lightning impulse withstand capability, and short-circuit strength. This ensures the constantly high quality of the transformers.

GEAFOL cast-resin transformers from Siemens Energy – technology makes the difference

Extremely high requirements on transformers for operational reliability and availability need to be met in various applications, e.g., when supplying electricity to critical and industrial infrastructures and data centres. This requires the highest quality standards in development and production design, as well as a great deal of expertise and experience. The same attention needs to be paid to the selection of materials and their precise processing to the structural implementation of high dielectric and mechanical strength. The superb quality is reflected in an excellent meantime between failure value (MTBF).

Siemens Energy has the necessary experience, having already installed more than 150,000 GEAFOL cast-resin transformers worldwide. Over the past five decades alone, the weight of the GEAFOL transformers has been reduced by more than one-third, with no reduction in output range or adverse effects on operational safety and reliability.

The core construction of Siemens Energy's GEAFOL transformers utilizes low-loss electric sheet steel, tailored to meet efficiency requirements, and painted to prevent corrosion under all conditions.

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Fig. 1 shows a GEAFOL with all the basic components.

1. The low-voltage windings, made of continuous aluminium (or copper) strips, are permanently bonded with a pre-impregnated insulating sheet, and receive a cast-resin finish.
2. The high-voltage windings consist of aluminium (or copper) foil windings, separated by two layers of insulation material.
3. The high-voltage coils are vacuum casted with a special, proprietary cast-resin mixture. The main components – epoxy resin and quartz powder – paired with process technology at the highest level, give GEAFOL transformers their superior electrical and mechanical qualities, and suitability for the most extreme environments and demanding applications, while being virtually maintenance-free and self-extinguishing.



Figure 1. GEAFOL with basic components

Over the years, the use of aluminium (and copper) foils and strips, insulated with high-grade plastic film, has prevailed. This technology has moved to the forefront in transformer manufacturing because the foil windings combine a simple technology with high electrical safety. The insulation is exposed to much lower electrical stress than in other types of windings.

Whereas turn-to-turn voltages in a conventional round-wire winding can add up to twice the interlayer voltage, the interlayer voltage of a foil winding never exceeds the single voltage per turn. The reason is the specific GEAFOL technology: all layers uniquely consist of a single winding, ensuring excellent power-frequency voltage strength and impulse voltage strength, with a very linear layer-to-layer and layer-to-ground voltage distribution (see Fig. 2).

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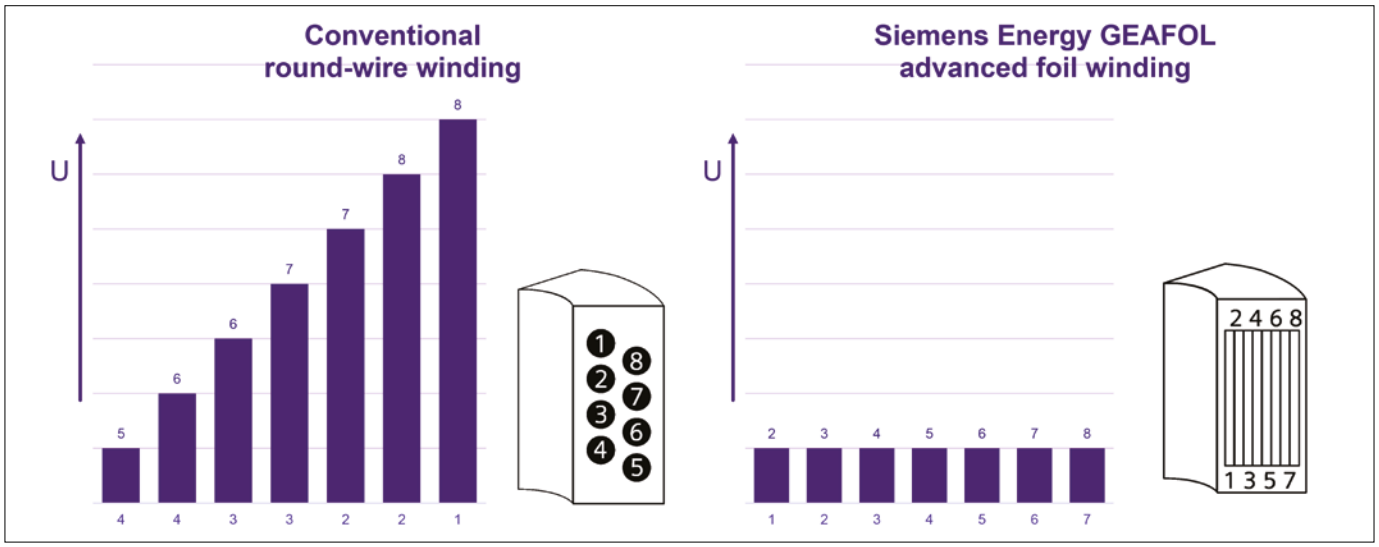


Figure 2. Voltage distribution of windings

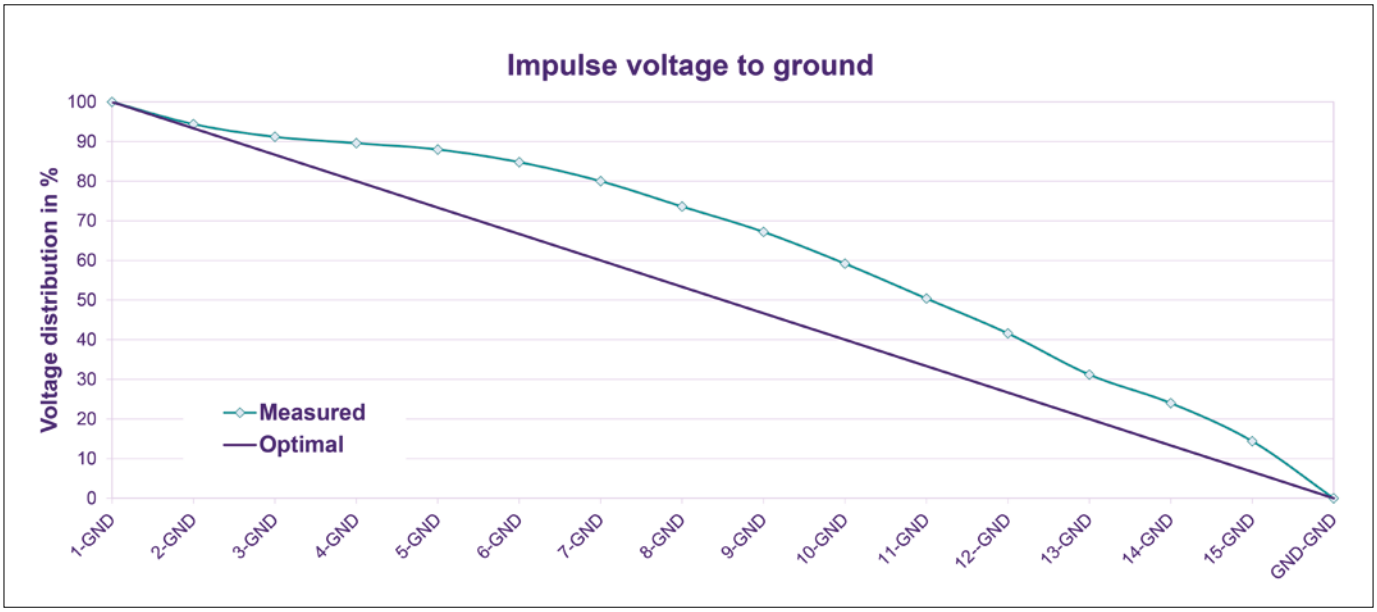


Figure 3. Impulse voltage distribution to the ground of GEAFOL transformer

This electrical behaviour of the GEAFOL has been confirmed by comprehensive testing according to IEEE Std C57.12.58. Fig. 3 shows the very uniform impulse voltage distribution over all sections of a high-voltage coil.

Customers benefit from the linear voltage distribution capabilities of a Siemens Energy GEAFOL through the prolonged lifetime

Siemens Energy GEAFOL cast-resin transformers and vacuum circuit breakers – a perfect combination

Customers benefit from the linear voltage distribution capabilities of a Siemens Energy GEAFOL throughout the prolonged lifetime, but especially when surges, short-circuits or transient voltages occur, the latter being caused by fast switching operations with vacuum circuit breakers.

When vacuum circuit breakers were first introduced – more than 30 years ago – cases of premature failures associated with fast switching transient overvoltages were reported. However, Siemens Energy's GEAFOL transformers have been successfully used in combination with this technology since the early days. Moreover, vacuum circuit breakers have improved significantly over the years, generally easing the stress on transformers in operation today.

Nevertheless, multiple tests were conducted under real installation conditions to confirm the empirical evidence of the successful combination of GEAFOL transformers and vacuum circuit breakers: The tests included a multitude of different GEAFOL transformers:

- Power ratings (100 kVA–3600 kVA)
- Voltage ratings (13.8 kV–34.5 kV)
- Loading (no-load, full load)
- Power factor (0.8–1)
- Vector groups
- Cable lengths (2.5–300 m)
- Vacuum circuit breaker designs
- Opening / closing operation at different phase angles.

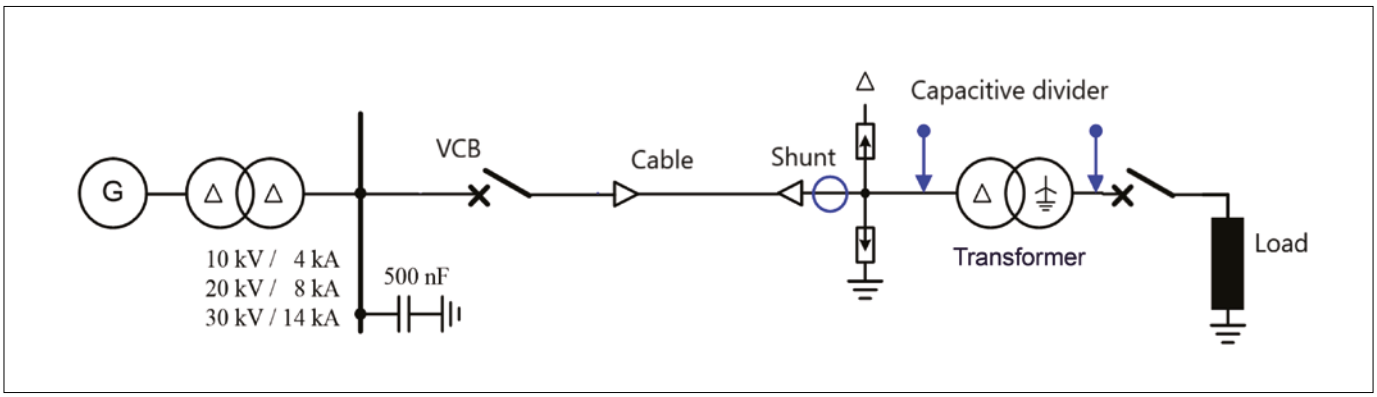


Figure 4. Testing setup under no-load conditions

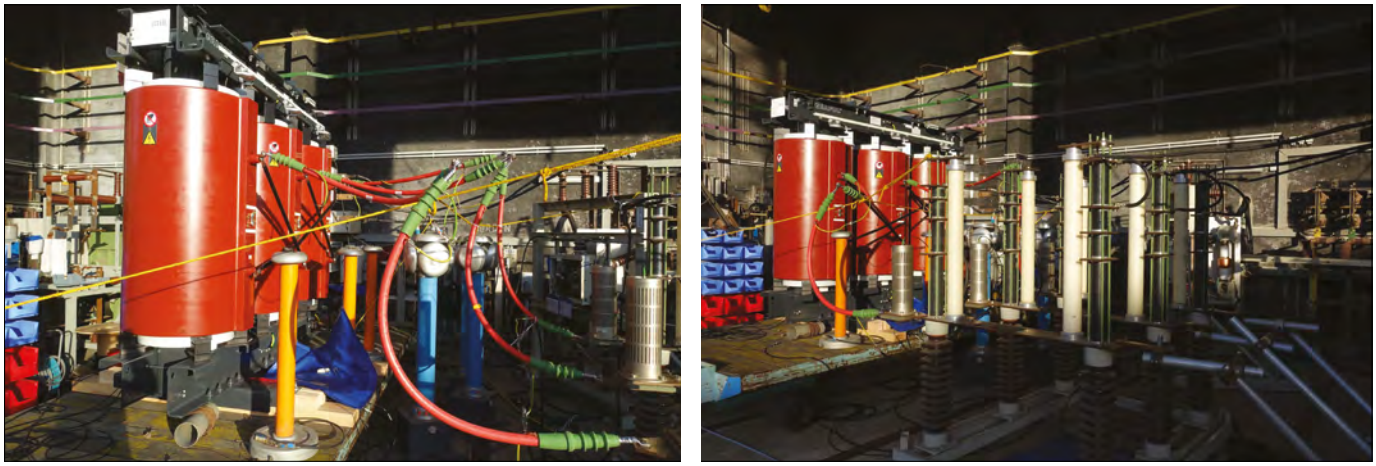
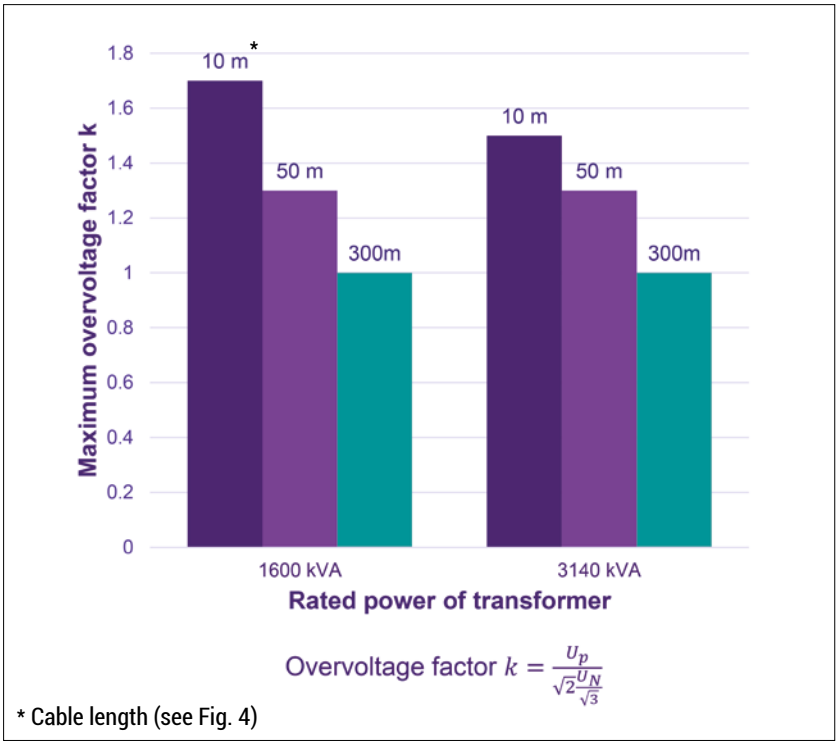


Figure 5. Testing environment



* Cable length (see Fig. 4)

Figure 6. Maximum overvoltage factors (k) recorded under no-load conditions

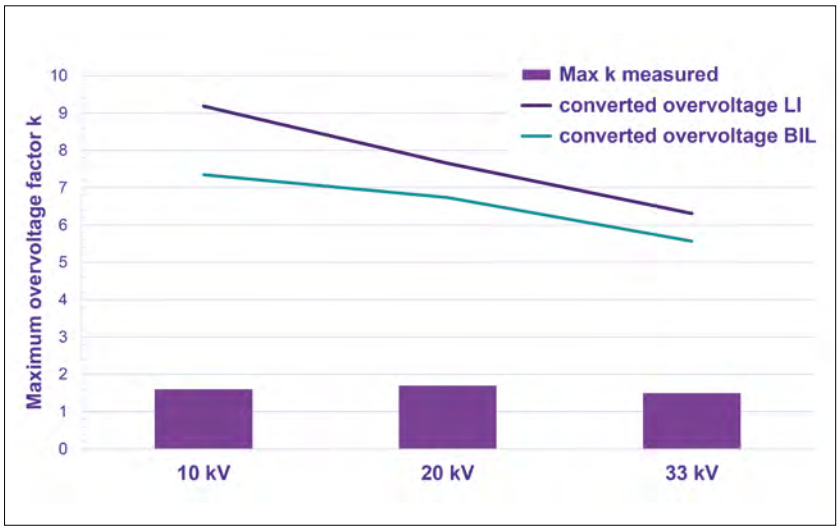


Figure 7. Measured overvoltage factors (k) recorded under no-load conditions versus converted overvoltage LI / BIL

During more than 500 switching operations, in which each configuration was tested several times, no critical overvoltage occurred (see Fig. 6). All the measured deflections, converted to their overvoltage factor k, remained well below critical thresholds, as defined by IEEE Std C57.12.01 as the basic insulation level (BIL) or by IEC 60076-11 as lightning impulse voltage (LI) (see Fig. 7).

In fact, during the test with the highest detected factor k of 1.7 p.u. under no-load conditions, the transients occurred only for milliseconds during a switching operation (see Fig. 8). The k value and the transient duration are well below Siemens Energy's routine testing values for freedom of partial discharge (see Fig. 9) and show impressively the high quality of Siemens Energy's GEAFOL transformers.

In the switching test under full load, the highest k factor recorded was 2.8 p.u. (see Fig. 10). This is still far below the design

Tests under no-load conditions showed k values and transient durations well below routine testing values for freedom of partial discharge, an impressive proof of high quality of Siemens Energy's GEAFOL transformers

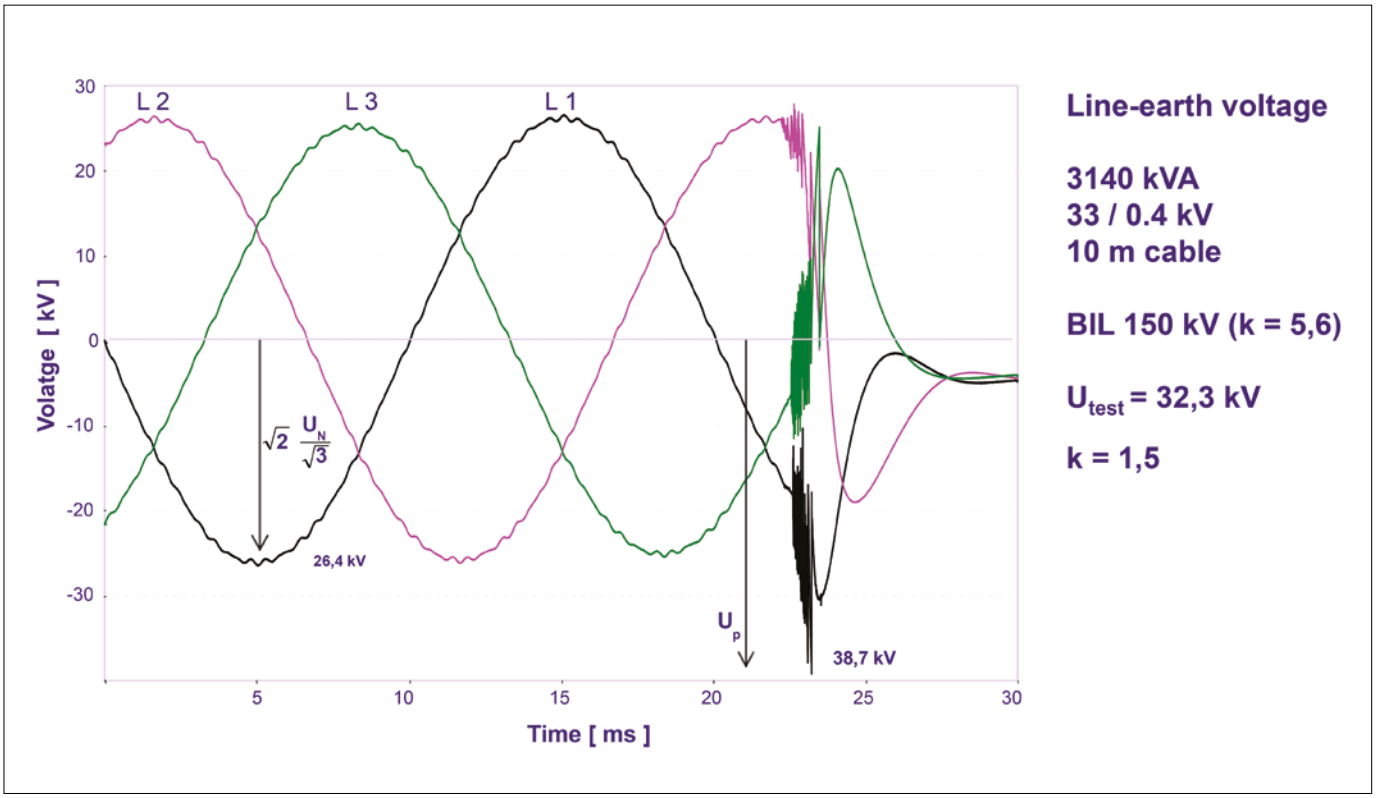


Figure 8. Transients during test with highest k value (no-load conditions)

Most of the switching operations under load triggered multiple re-ignitions with different repetition frequencies, but none of them caused any damage to the insulation system of the GEAFOL transformer

value for the lightning impulse or basic insulation level (LI / BIL). Most of the switching operations triggered multiple reignitions with different repetition frequencies (see Fig. 11), but none of them caused any damage to the insulation system of the GEAFOL transformer. After completing the switching test, every transformer again passed the routine test at the 100 % test level.

Finally, tests were performed to see what happens when the GEAFOL transformer is switched off during inrush (see Fig: 12). This is an operation that is usually prevented by the setting of the circuit

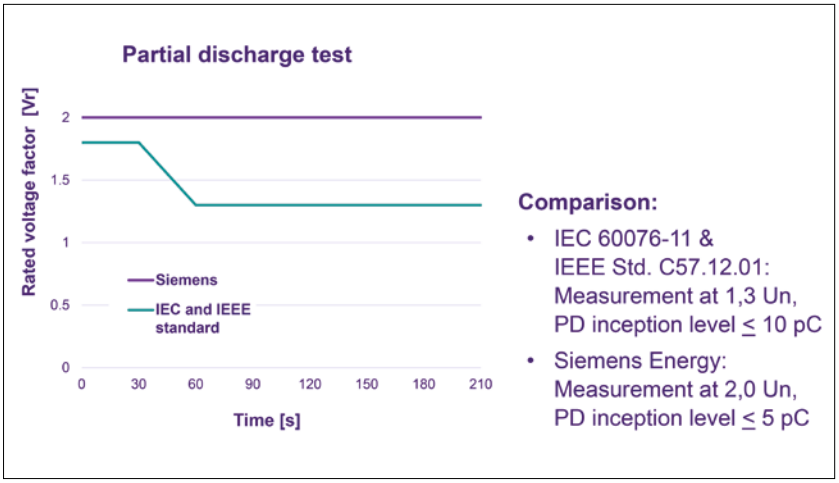


Figure 9. Siemens Energy's routine testing values for freedom of partial discharge (exceeding IEC and IEEE standard)

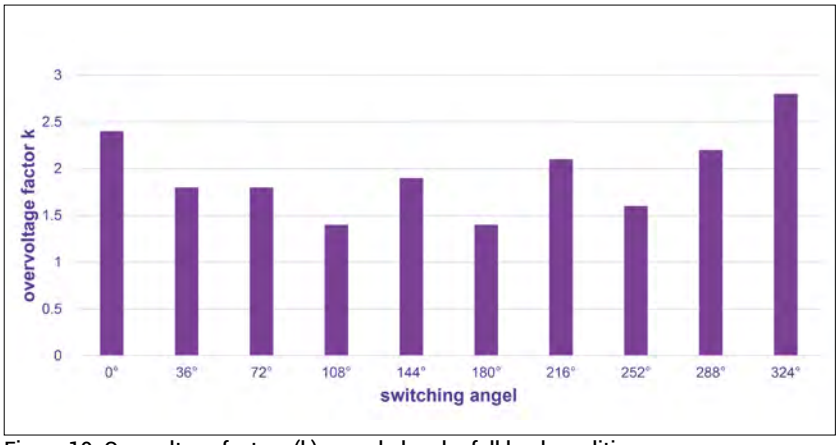


Figure 10. Overvoltage factors (k) recorded under full load conditions

The inherent linear voltage distribution of the GEAFOL transformers prevents weak spots in the turn-to-turn insulation and leads to less voltage stress on the naturally more exposed line-end sections of the coil, thus minimizing transient oscillations

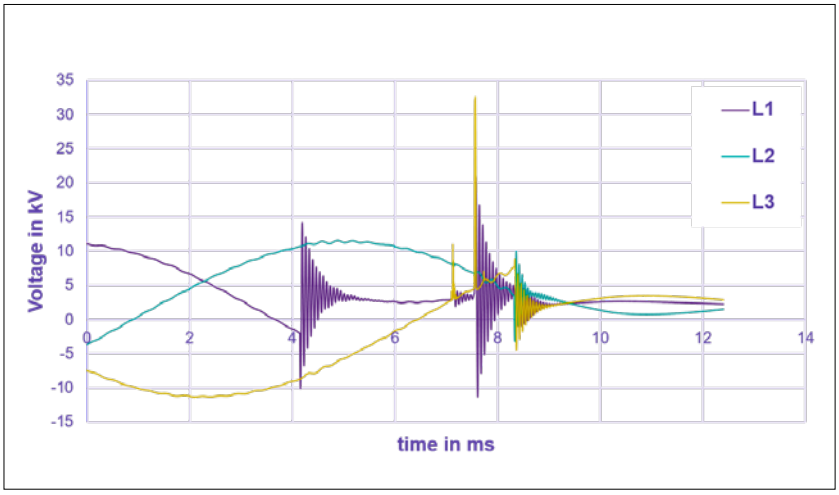


Figure 11. Multiple reignitions after switch of under load

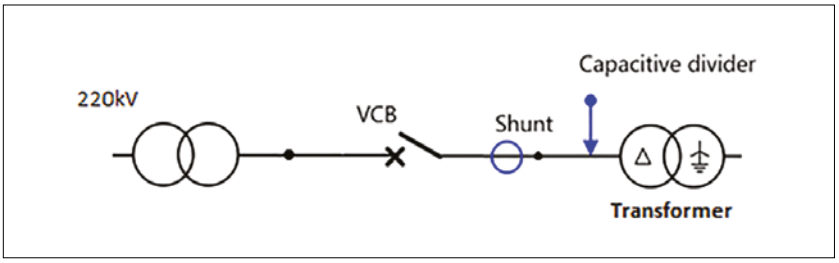


Figure 12. Testing setup switching during inrush

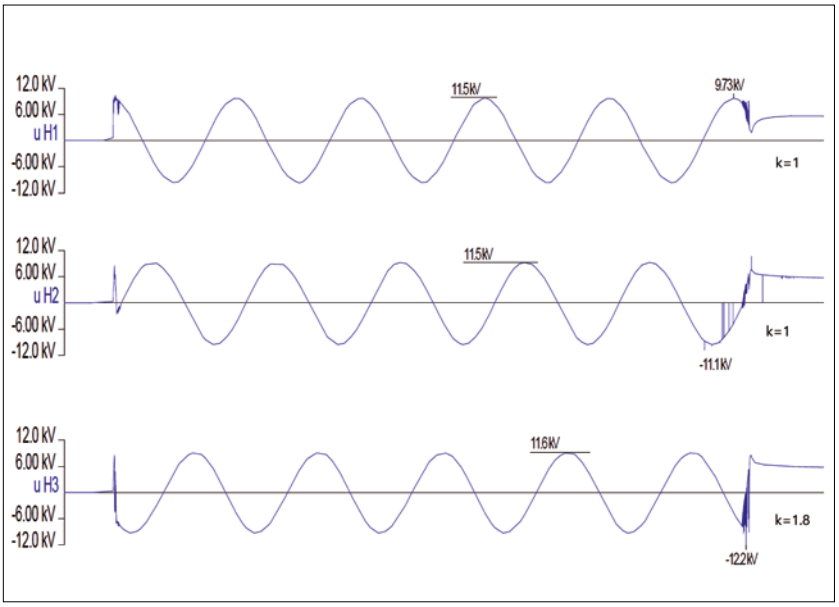


Figure 13. Maximum overvoltage factors (k) recorded during switching during inrush

breaker. In several switching tests with a vacuum circuit breaker combined with a GEAFOL transformer under inrush conditions with a declining test duration from 3 to 0.1 s, it was proven that Siemens Energy's GEAFOL cast-resin transformers can withstand this kind of switching operation. The highest measured overvoltage factor for inrush switching was k = 1.8 p.u. (see Fig. 13), which is only slightly higher than the 1.7 p.u. measured in no-load switching and still far below critical values.

Siemens Energy's GEAFOL cast-resin transformers – always a good choice

All the testing has demonstrated the safety and reliability of Siemens Energy's GEAFOL cast-resin transformer design. The inherent linear voltage distribution not only prevents weak spots in the turn-to-turn insulation but also leads to less voltage stress on the naturally more exposed line-end sections of the coil, thus minimizing transient oscillations.

In combination with vacuum circuit breakers, Siemens Energy's GEAFOL cast-resin transformers can be operated without the need for expensive RC-snubber circuits. The transformers have proven their inherent transient voltage withstand capabilities over many decades in the field and during comprehensive testing. Even when switching loads with a power factor (cos φ) equal to or above 0.75, no additional measures are required (for power factors (cos φ) below 0.75, surge arresters are recommended).

Covering an output range from 100 kVA to 50 MVA, with operating voltages up to 66 kV, Siemens Energy's cast-resin transformers have earned a worldwide reputation over the past half-century for high efficiency and unsurpassed safety, quality, and reliability. They can be utilized universally and globally. Installation examples include data centres, high-rise buildings or hospitals, rectifier and traction duty, offshore installations and vessels, underground mining, renewable power, conventional and nuclear power plants and many more.

https://siemens-energy.com/geafol