SAFE AND RELIABLE TRANSIENT-PROTECTED TRANSFORMERS

Depending on system characteristics, switching medium-voltage (MV) fast-acting breakers may produce fast transient overvoltages that can damage transformers. By introducing varistors along the windings of the transformer, ABB Power Grids* can eliminate such transient and associated effects →01.

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One of the most intimidating tasks faced by a data center manager is that of switching actions within the site's electrical network. Depending on system characteristics, switching of MV fast-acting breakers (either vacuum- or gas-insulated) can produce fast-transient overvoltages throughout system equipment that damage electrical insulation and, over time, may lead to failures. These failures are typically not repairable in the field, resulting in prolonged outages.

A complex problem
This issue with distribution-class switching transients dates back to the arrival of vacuum circuit-breaker technologies in the early 1990s. The ability to interrupt current under vacuum was a step change for electrical network design because it allowed for much higher currents to be interrupted safely and much faster than was the case with air breakers. It was not until a decade later, however, that it was discovered that this new current-chopping ability was subjecting network electromagnetic devices to extreme voltage transients. New failure modes were being observed in distribution transformers, control and measurement transformers and motors. Closer investigation showed that switching transients had become the worst voltage stress that equipment could experience during typical operation.

All circuit breakers interrupt the current somewhat before a natural current zero crossing at an amplitude referred to as the "current chopping level." As the current is chopped, magnetic energy is trapped in the inductances on the load side of the circuit breaker, where it gives rise to a current that circulates between the capacitances and inductances there. This current flow can generate a transient overvoltage. The difference between the voltage potential upstream of the circuit breaker and these transient overvoltages is known as the transient recovery voltage (TRV). If the circuit breaker contacts are not far enough away from each other when current chopping occurs, the TRV may cause a reignition across the breaker contacts. Further, if the TRV increases faster than the increasing electrical withstand capability of the opening circuit breaker contacts, multiple reignitions may occur →02.

Exacerbating the problem, all three poles of the circuit breaker do not interrupt at the same instant. When the current in the first pole is interrupted somewhat before its natural current zero crossing, current continues to flow in the two other poles. If a reignition occurs in the pole that interrupted first, this will give rise to a high-frequency oscillating current that could also flow through the two poles that have not yet interrupted. This contribution of high-frequency currents may cause current zero crossings and extinguishing of the arcs in the two other phases. This zero crossing can be regarded as a type of chopping of the current at a significantly higher amplitude than the ordinary chopping level. This level could be close to the peak value of the load current and is referred to as "virtual current chopping." It occurs due to the unique property of the vacuum circuit breakers' ability to interrupt high-frequency currents and could generate overvoltages of significantly higher amplitude [1].

— As the current is chopped, magnetic energy is trapped in the inductances on the load side of the circuit breaker.

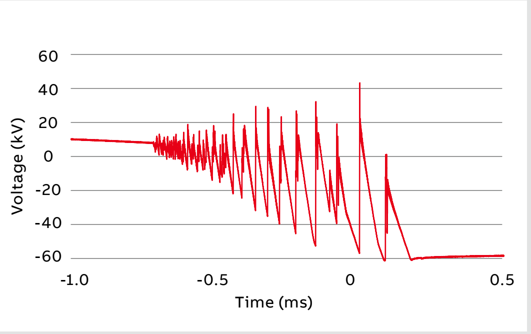
A last challenge is presented by the trapped currents circulating between capacitances and inductances on the load side of the circuit breaker. These currents oscillate at sweeping, high frequencies (into the MHz range) within magnetic equipment. Typical natural frequencies of distribution transformers are between 30 and 40 kHz. Since the trapped circulating currents sweep through these ranges, they may excite the natural frequencies inside the equipment, causing voltage amplification due to harmonic resonance →03.

— 01 TVP for distribution transformers places varistors strategically along the windings of the transformer to limit transient overvoltages from reignitions that may occur inside of the breaker or from any amplified voltages from harmonic resonance inside the transformer.

— 02 Multiple reignitions with resultant voltage transients in an unprotected distribution transformer during a single switching event. If experienced frequently, over time, these transients lead to insulation failures.

— 03 Capture of harmonic resonance occurring across the terminals of the distribution transformer.

— 04 Dry-type distribution transformer equipped for winding varistors (red highlight) and traditional surge arresters (red dotted highlight).



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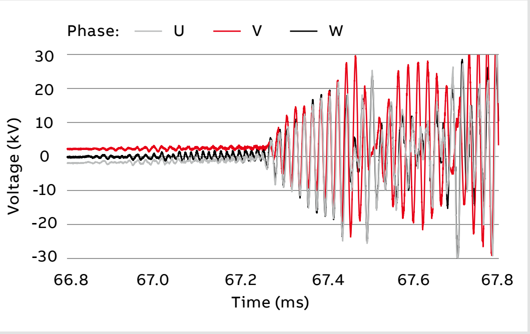

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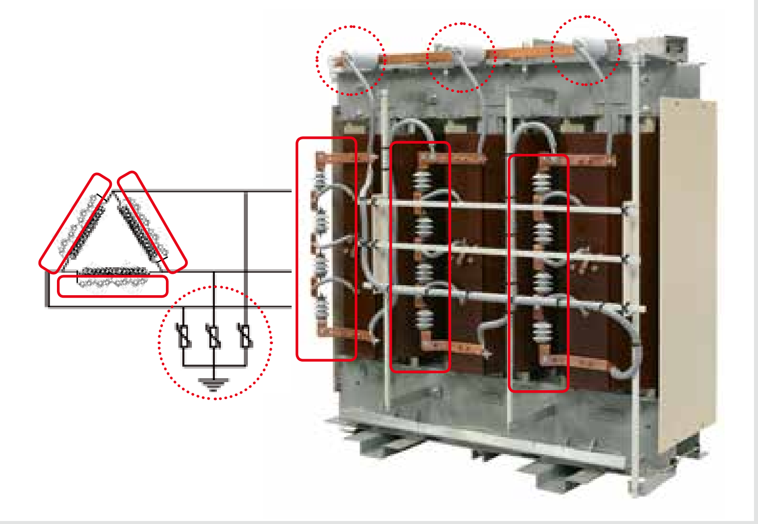

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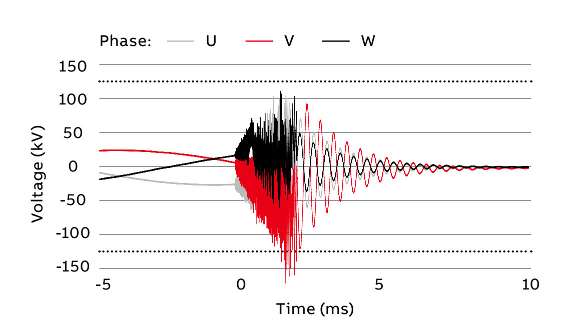
*A planned joint venture between Hitachi and ABB.



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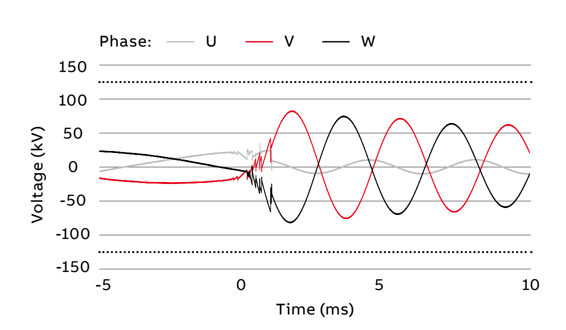

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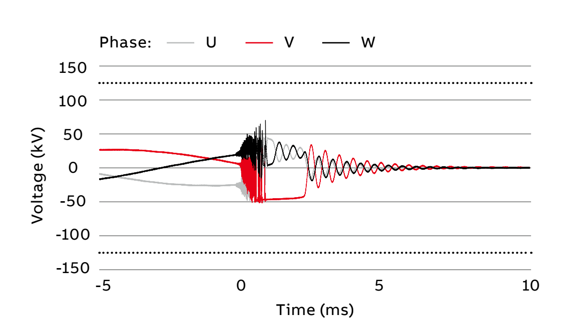

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Simple solution

To meet the need for reliable commissioning and load-bank switching operations commonly found in data centers, ABB set out to develop a solution for transformers that can operate safely with fast-acting breakers. ABB evaluated many existing solutions in their 20 kV distribution network test lab in Vasteras, Sweden. All existing solutions (such as RC snubber circuits, MV chokes, surge arresters and transformer hardening) were found to be insufficient in controlling peak voltages during switching and/or unable to prevent voltage amplification from harmonic resonance. Some approaches also had the added burden of first requiring a system study in order to arrive at a proper design.

With insights gleamed from over 10 years of testing existing and new solutions, ABB engineers were able to address the voltage stress from network switching with a simple technology: winding varistors. ABB's Transient Voltage Protection™ (TVP™) for distribution transformers places varistors strategically along the windings of the transformer in proprietary arrangements to limit transient overvoltages from reignitions that may occur inside of the breaker as well as from any amplified voltages from harmonic resonance inside the transformer →01, 04.

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Winding varistors act as pressure relief valves that provide a secondary current path.

Winding varistors act as pressure relief valves that provide a secondary current path and prevent voltage peaks inside the winding from reaching levels that could damage the transformer insulation →05. Combined with advanced winding design, the TVP technology controls peak voltages that might occur without expensive system studies or the need to know the characteristics of the connected system. Also, since the varistors provide a secondary path for fast transients, they protect all other magnetic equipment on the same side of the breaker.

Combining the TVP with dry-type transformers also eliminates additional potential catastrophic failure modes – eg, fires, explosions, or environmental leaks – by doing away with liquids for dielectric insulation and cooling, making this solution the safest transformation for distribution networks. Risk of liquid-filled capacitor failures (inside RC snubber circuits) is also removed. Because of these additional safety features, dry-type transformers equipped with TVP not only eliminate switching failure modes but also provide the safest form of distribution transformation →06.

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05 Comparison of transformer switching protection methods.

05a Unprotected distribution transformer during network switching.

05b Distribution transformer with a close-coupled RC snubber circuit.

05c Distribution transformer with ABB's TVP.

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06 TVP installed on a new transformer at an ABB factory.

The future of safety

The next step in providing safe network distribution is to not only protect the system from harmful events (such as switching transients) but to identify the level of risk before a potential failure event occurs. Advancements in digitization are enabling network managers to identify potential problem areas and act before they lead to significant costs.

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The transformers self-monitor voltage, current, temperature, pressure and climate.

Digital transformers, like ABB's TXpert™, are equipped with advanced monitoring and analytics to feed cautionary information to managers on slow-developing or fast-acting network issues. The transformers self-monitor voltage, current, temperature, pressure and climate and convert those signals into a power quality assessment, a measure of transformer consumed life and maintenance needs. All processing is done at the transformer or in an edge network for the fastest and most secure response.

Such digital features allow analytics that enable network managers to put condition-based maintenance onboard the transformer and achieve more predictability of asset life consumption. In time, the goal is to give network managers full confidence in the functionality of their systems and to remove any routine outages in the future. •

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References

[1] E. Lindell and L. Liljestrand, "Effect of different types of overvoltage protective devices against vacuum circuit-breaker-induced transients in cable systems," IEEE Xplore, volume 31, issue 4, pp. 1571 - 1579, 2015.