Snubbers:

Protecting medium-voltage transformers from electrical transients

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Protecting medium-voltage transformers from electrical transients is vital in the designing and commissioning of electrical distribution and protection systems. This article details how transients are produced and describes a mitigation method using snubbers.

A snubber is a resistor-capacitor (RC) network that is designed for the system. Snubbers are a cost-effective method of reducing switching-induced transients. At many installations that use medium-voltage switching, transformer damage is often attributed to lighting. However, this damage is likely caused by transients induced by switching. In a facility with on-site power generation and switching at medium-voltage levels, a power outage results in either a transfer between power sources or a transfer to the generators. The result could induce a transient that could damage the transformer; a snubber network can provide additional protection against damage.

Switching transients

Switching transients occur when circuit breakers switch transformer primaries in medium- and high-voltage systems, such as automatic switching between utility services or on-site power generation. They also can happen during planned transfers from utility to generator, such as preceding a thunderstorm or routine testing. When a breaker interrupts current flow, an arc develops across the breaker contacts. Since the current interruption usually occurs somewhere other than the current zero crossing point, the arc will remain until the current crosses zero. The result is a voltage developing across the contacts, known as the transient recovery voltage (TRV).

To help prevent contact wear, breaker manufacturers provide mechanisms to ensure that the dielectric strength between the contacts increases faster than the TRV develops. As a result of the TRV, a high-frequency transient is induced in the system. Figure 1 represents a graph of current interruption, arc voltage, and the resulting TRV. When the current is interrupted, the resulting TRV has significant high-frequency content. This is a direct result of the quick interruption, or current chopping, of the load current. These transients normally are not produced during fault conditions due to the rapid decay of the energy levels during a fault.

To minimize space requirements, modern medium-voltage circuit breakers use vacuum or gas as the dielectric medium. Vacuum has a higher dielectric than air, so the distance required between contacts is much smaller than that for air breakers. The shorter distance increases the speed of the interrupting cycle, which results in current chopping and the introduction of high-frequency transients into the system. Transient level and frequency are functions of the physical distance between the breaker and transformer, transformer construction (virtual path identifier, cast coil, oil filled, basic impulse level ratings), the type of load being switched, and the switching characteristics of the breaker.

If these transients are at the natural resonance frequency of the system, then there is the possibility of internal oscillatory voltages developing in the primary windings of the transformer. This voltage is limited only by the small losses at or near the resonance of the system. The voltage can be significantly higher than the insulation ratings and lead to winding failure. For example, a 100-V primary would transform with 100 windings, which results in the turn-to-turn winding insulation that needs to be rated for 1 V at 60 Hz. Impress a voltage signal at the natural resonance of the transformer and the result may be 10 to 20 V between the windings, at resonance. This could damage the windings. It is important to remember that this is a frequency-related issue and not necessarily a voltage issue, and most surge protective devices are not designed to suppress this energy.

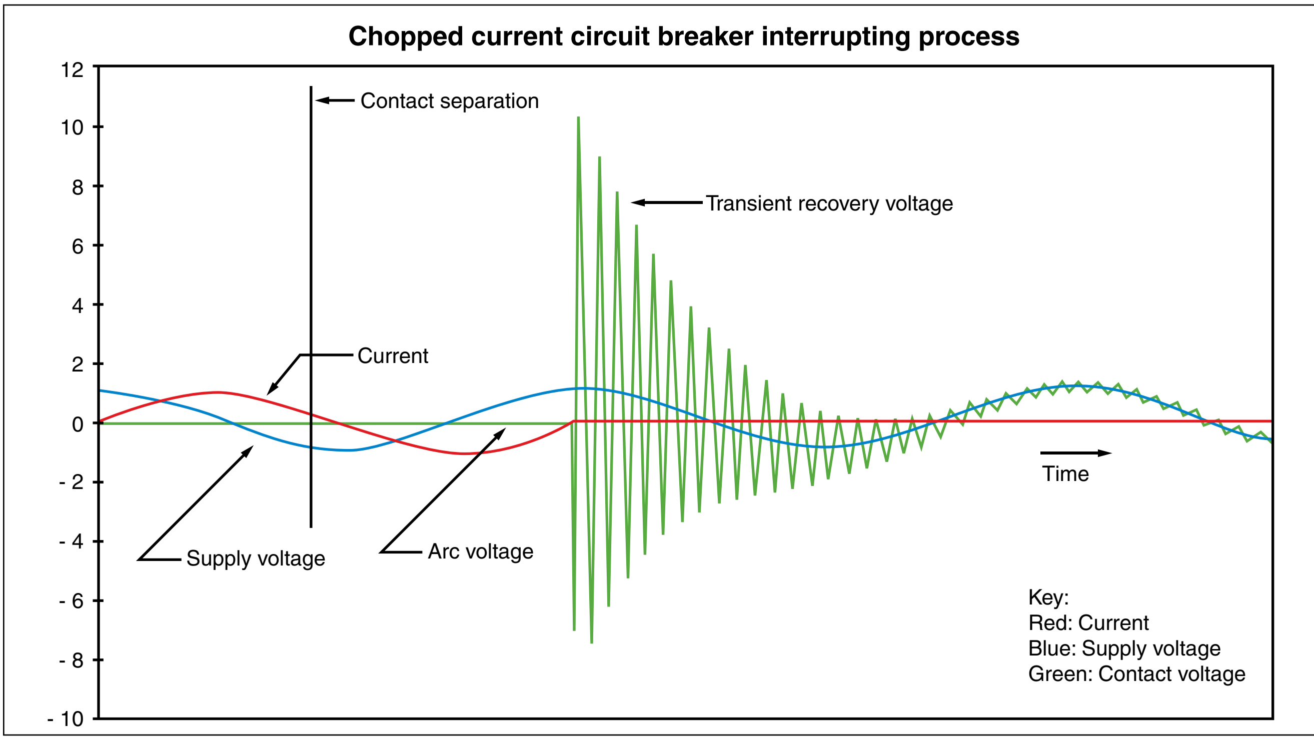
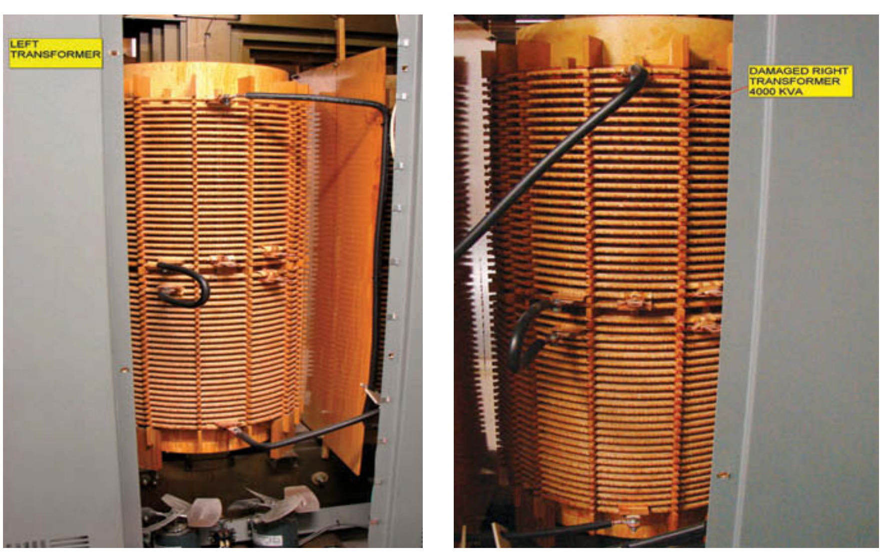


Figure 1 represents a graph of current interruption. Once interrupted, the resulting TRV has significant high-frequency content.
Source: Bala Consulting Engineers

Commissioning projects

During a recent maintenance and commissioning project at an international brokerage firm, technicians experienced several incidences of switching-induced transients. A worker was operating the primary circuit breakers when he heard a loud pop and saw a bright flash from the transformer enclosure. All work was stopped and the transformer was replaced, even though factory testing revealed no defects. The breakers had been operated at least 30 times prior to this occurrence. These events occurred during switching of the primary circuits of medium-voltage, dry transformers from 2,500 to 4,000 kVA, with vacuum circuit breakers. This portion of the switchgear is part of a main-tie-main, PLC-controlled, 4 MVA, 13.2 kV-distribution system.



The 4,000 kVA, vacuum pressure impregnation transformer was damaged as a result of the switching transients.
Source: Bala Consulting Engineers

The images below show the 4,000 kVA, vacuum pressure impregnation transformer that was damaged as a result of this event. The vacuum circuit breaker is connected to the transformer with 50 ft of 15 kV cable (Figure 3) and an unloaded 2-MW UPS plant was on the secondary side of the transformer.

An investigation of the event revealed that the flash resulted from switching transients. This realization led the engineering team to research possible mitigation solutions.

Mitigation methods

There are several ways to reduce the effects of switching transients, including transformer-winding design and series inductors. However, the installation of an RC-snubber network will work well in situations similar to those mentioned above. The RC-snubber network lowers the frequency of the transient voltage applied to the transformer primary below the resonance frequency of the circuit. It reduces the development of the oscillatory voltages and provides a low impedance path to ground for the transients.

Figure 2 represents an RC-snubber network that was specifically designed for and

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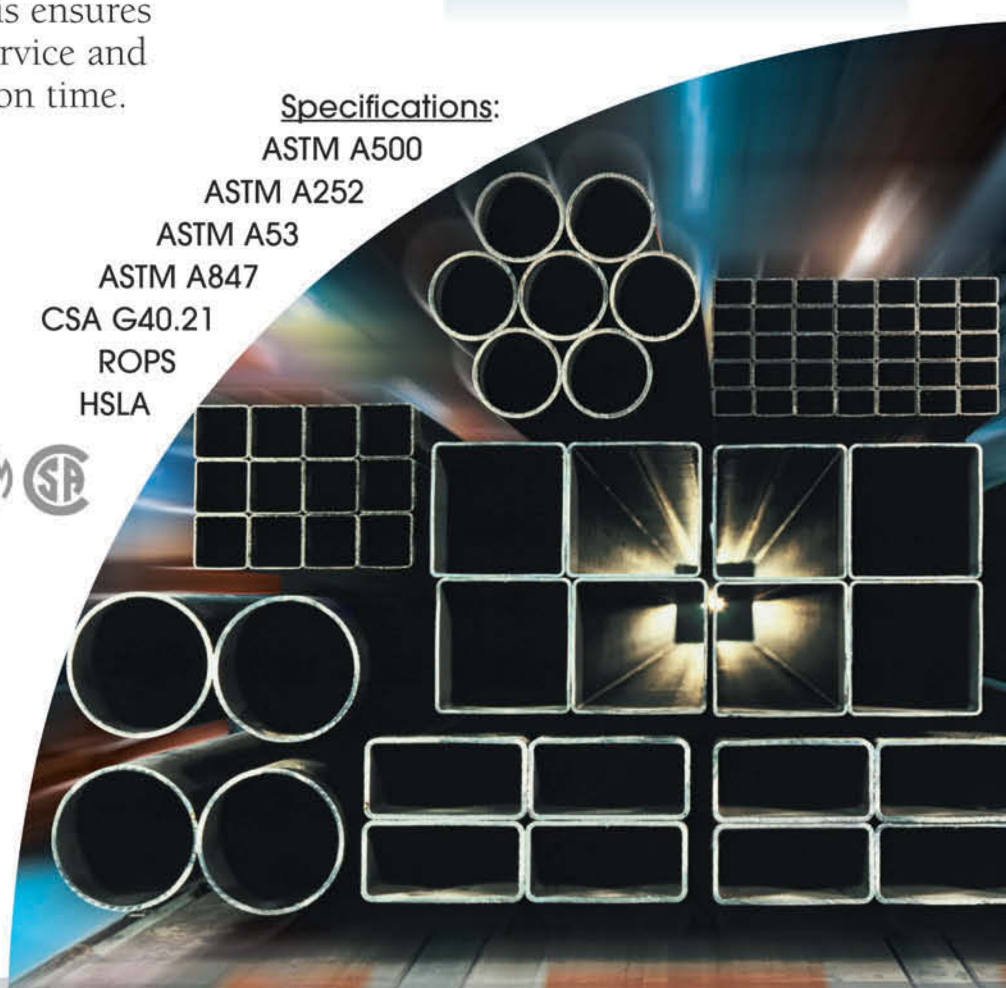

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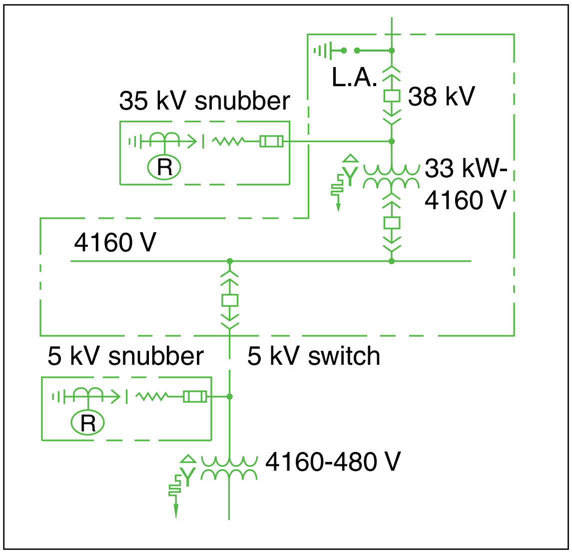


Figure 2 is an RC-snubber network that was specifically designed and installed on a medium-voltage distribution system that supports a mission critical data center.
Source: Bala Consulting Engineers

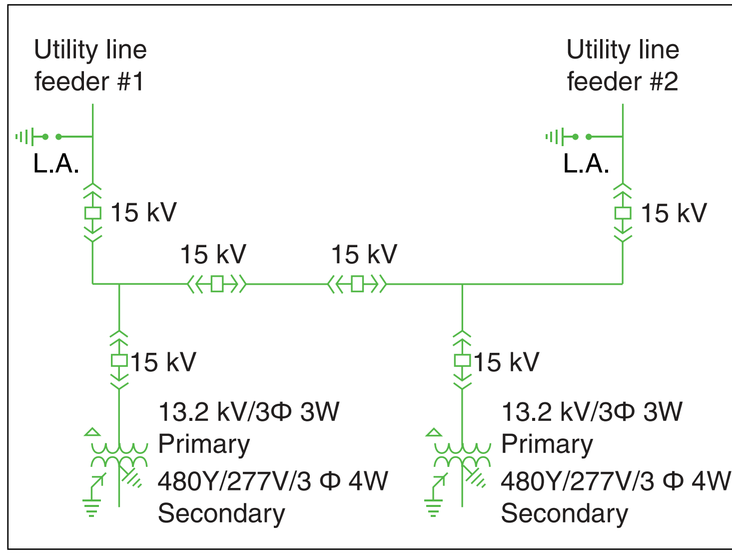
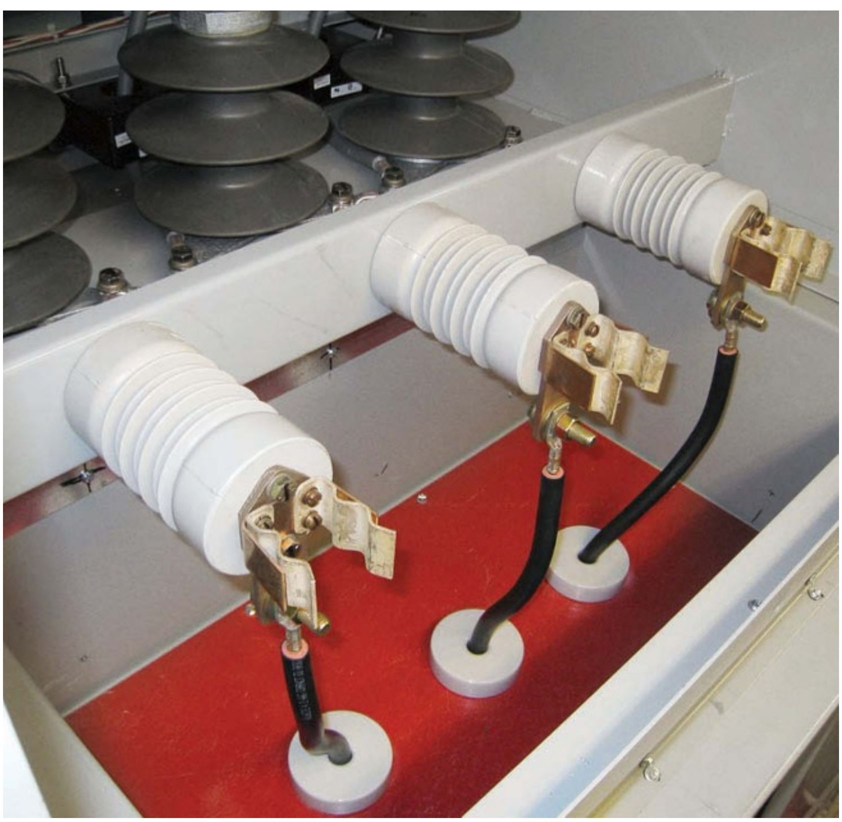


Figure 3 shows the relationship of the vacuum circuit breaker to the damaged transformer that experienced the flash.
Source: Bala Consulting Engineers



The RC-snubber will provide a low impedance path to the ground for energy, especially when switching with vacuum breakers. *Source: Bala Consulting Engineers*

installed on a medium-voltage distribution system that supports a mission critical data center. The data center's system had experienced a flashover during routine maintenance, but no arc flash incidents have occurred since the installation of the snubber. Previously, these transformers were protected at the rated voltages with surge protective devices and lightning arrestors on the primary. However, the transients' voltage level is often below the clamping level of these protective devices, so they do not provide protection.

Switching induced transients are closely related to circuit breaker characteristics and load characteristics, and they can be difficult to predict. When switching medium-voltage transformers with vacuum breakers, it is a good practice to at least leave space for future installation of a snubber network.

Resolution of these issues may result from the ongoing review of IEEE Draft PC57.142/D1.7. cse

Young is the electrical department manager for Bala Consulting Engineers. With 20 years of electrical engineering experience, Young specializes in power distribution systems for mission critical facilities. Young would like to acknowledge David Swindler, PE, for his contribution to the article.