

TechTopics No. 03

Vacuum vs. SF₆

The technical literature over the past several decades includes a number of papers that discuss the merits and demerits of vacuum and SF₆ interrupting technologies. Of course, most of the papers are biased in favor of one of the competing technologies, although several appear to strive for an unbiased or neutral point of view. Perhaps the principle arguments used by advocates of SF₆ are:

- A SF₆ interrupter can be equipped with a low-pressure alarm switch to give indication that gas pressure inside the interrupter has been lost
- Interruption in SF₆ is “soft” (no current chopping).

We believe that these issues are not significant relative to Siemens vacuum interrupters, and that the facts strongly favor the use of vacuum as an interrupting medium.

Leak detection

SF₆ proponents argue that a vacuum circuit breaker needs a “loss of vacuum detector” to be equivalent to an SF₆ circuit breaker with a low-pressure alarm switch. To our knowledge, no supplier has a practical loss of vacuum detector on a vacuum circuit breaker. Over the years, various efforts have been made to develop one, but they always stumble on one seemingly immutable law of the universe. It appears that any means to provide an indication (or remote alarm) on loss of vacuum requires changes to the interrupter construction that radically increase the likelihood that a leak will occur.

Further, the failure rate of today’s interrupters is so low that loss of vacuum is no longer a significant concern. In the early 1960s, it was a big problem.

For comparison, consider the problems of an air magnetic circuit breaker. No air magnetic circuit breaker includes a means to indicate that the arc chutes are not installed, or are installed incorrectly. The result of incorrectly installed arc chutes is usually complete circuit breaker destruction and considerable damage to one or more switchgear cubicles. Yet, air magnetic circuit breakers were used for decades and no one clamored for a “loss of arc chute integrity” indicator!

The proponents of SF₆ circuit breakers continually raise the specter of catastrophic failure of circuit breakers on loss of vacuum. To promote their SF₆ technology, they feature their low-pressure alarm switch option. The only reason they need this option is because leaks in SF₆ are a virtual certainty!

The reason that leaks are so much more likely with SF₆ than vacuum relates to their construction. A vacuum interrupter is constructed with all connections between dissimilar materials made by brazing or welding. No organic materials are used. In the early years, many hand production techniques were used, especially when borosilicate glass was used for the insulating envelope, as it could not tolerate high temperatures. Today, machine welding and batch induction furnace brazing are employed with extremely tight process control. The only moving part inside the vacuum interrupter is the copper contact, which is connected to the interrupter end plate with a welded stainless steel bellows. Since the bellows is welded to the contact stem and the interrupter end plate, the failure rate of this moving connection is extremely low. The basic design (welding/brazing) and the sophisticated process controls account for the extremely high reliability of Siemens vacuum interrupters. As of 2010, the mean time to failure (MTTF) for Siemens power vacuum interrupters had exceeded 57,000 interrupter years, illustrating that loss of vacuum is an extremely remote occurrence.

In contrast, an SF₆ interrupter requires a sliding or rotating seal at the point where the mechanism penetrates the wall of the interrupter chamber. These seals can age and leak, so that a means to alarm on low pressure becomes mandatory.

The typical SF₆ circuit breaker has twice the number of parts in the high voltage circuit as the equivalent vacuum circuit breaker. The typical number of moving parts in the high voltage circuit is also twice as many. More significant, the number of inaccessible moving parts (under SF₆ or vacuum) is about 10 times as great! This last point is very significant, as moving parts obviously have a higher failure rate than non-moving parts. The greater number of moving parts in the SF₆ circuit breaker dictates that it must be less reliable than a vacuum circuit breaker. In some cases, an SF₆ interrupter can be repaired, but only at the factory, which means that in most cases, the method of repair will in fact be replacement.

The supporters of SF₆ technology frequently claim that a leaking SF₆ interrupter will still interrupt rated fault current one time. While this may sometimes be true, it is seldom true for all ratings, especially the high interrupting ratings common in metal-clad switchgear and outdoor substation type circuit breakers. The dielectric strength and interrupting capacity of SF₆ circuit breakers depends on the existence of adequate gas pressure. If the SF₆ pressure drops to atmospheric level, there is no way of telling whether the arc chamber contains SF₆, air or a mixture. As a result, there is no way to predict with confidence the performance of the interrupter under such conditions.

'Soft' interruption

The other argument used extensively by advocates of SF₆ technology is that vacuum circuit breakers chop current prior to a natural current zero, and gas breakers do not. This is not completely true, as chopping can occur with any type of interrupting medium, including oil, air magnetic, vacuum, SF₆ and air blast circuit breakers. Further, current chopping is a statistical phenomenon, and also depends on the characteristics of the circuit being switched and the amount of current interrupted. There are numerous papers that discuss application of vacuum circuit breakers in detail. While current chopping was a major concern in the 1960s, when the common vacuum technology employed copper-bismuth contacts, it is no longer an issue with today's chrome-copper contacts.

The common areas of concern with application of vacuum circuit breakers are transformers and motors. Siemens application recommendations are contained on page 26 of the selection and application guide for type GM-SG switchgear. We recommend that all transformers have full BIL rating. Any transformers that have reduced BIL (i.e., open dry-type designs) require surge protection. This can be provided by the Siemens type 3EF zinc oxide surge limiter, or by a conventional zinc oxide surge arrester. Limiters and arresters differ in several fundamental respects.

The type 3EF surge limiter can absorb the trapped energy associated with a vacuum interruption, whereas a surge arrester has a greater energy absorption capacity to deal with system phenomena, including lightning strikes and switching surges from all sources. The 3EF surge limiter has a lower (i.e., better) protective voltage level than an equivalent surge arrester.

Further information on the subject of voltage surges, which can occur with vacuum interrupters, and their impact on equipment selection is contained in "Surge Limiters for Vacuum Circuit Breakers," by S. H. Telander, et. al., which appeared in the July/August 1988 issue of the IEEE Transactions on Industry Applications. In capsule form, our recommendations for vacuum circuit breaker application (vacuum contactor application recommendations differ) are as follows:

1. For transformers of full BIL rating, no additional protection is needed.
2. For transformers of reduced BIL rating, add some form of protection (either surge limiters at the switchgear, surge capacitors at the transformer or surge arresters at the transformer).
3. For motors with locked rotor current under 600 A, add surge protection (surge limiters at the switchgear, surge capacitors at the motor or surge arresters at the motor).
4. For motors with locked rotor current over 600 A, no additional protection is needed.

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