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TechTopics No. 02

Loss of vacuum

If a vacuum interrupter should lose vacuum, several operating situations should be considered:

a. With contacts open

b. When closing

c. When closed and operating normally

d. When opening and interrupting normal current

e. When opening and interrupting a fault.

Cases a, b and c are relatively straightforward. Generally, the system sees no impact from loss of vacuum in such a situation. Cases d and e, however, require further discussion.

Suppose there is a feeder circuit breaker with a vacuum interrupter on phase 3 that has lost vacuum. If the load being served by the failed interrupter is a delta-connected (ungrounded) load, a switching operation would not result in a failure. Essentially, nothing would happen. The two good phases (phase 1 and phase 2, in this example) would be able to clear the circuit, and current in the failed interrupter (phase 3) would cease.

The alternative case of a grounded load is a different situation. In this case, interruption in the two good phases (phase 1 and phase 2) would not cause current to stop flowing in phase 3, and the arc would continue to exist in phase 3. With nothing to stop it, this current would continue until some backup protection operated. The result, of course, would be destruction of the interrupter.

Since the predominant usage of circuit breakers in the 5-15 kV range is on grounded circuits, we investigated the impact of a failed interrupter some years ago in the test lab. We intentionally caused an interrupter to lose vacuum by opening the tube to the atmosphere. We then subjected the circuit breaker to a full short circuit interruption.

As predicted, the "flat" interrupter did not successfully clear the affected phase, and the "flat" interrupter was destroyed. The laboratory backup breaker cleared the fault.

Following the test, the circuit breaker was removed from the switchgear cell. It was very sooty, but mechanically intact. The soot was cleaned from the circuit breaker and the switchgear cell, the faulty interrupter was replaced, and the circuit breaker was re-inserted in the cell. Further short circuit interruption tests were conducted the same day on the circuit breaker.

Field experience in the years since that test was conducted supports the information gained in the laboratory experiment. One of our customers, a large chemical operation, encountered separate failures (one with an air magnetic circuit breaker and one with a vacuum circuit breaker) on a particular circuit configuration. Two different installations, in different countries, were involved. They shared a common circuit configuration and failure mode. The circuit configuration, a tie circuit in which the sources on each side of the circuit breaker were not in synchronism, imposed approximately double rated voltage across the contact gap, which caused the circuit breaker to fail. Since these failures resulted from application in violation of the guidelines of the ANSI/IEEE standards, and greatly in excess of the design ratings of the circuit breakers, they are not indicative of a design problem with the equipment.

However, the damage that resulted from the failures is of interest. In the case of the air magnetic circuit breaker, the unit housing the failed circuit breaker was destroyed, and the adjacent switchgear units on either side were damaged extensively, requiring significant rebuilding. The air magnetic circuit breaker was a total loss. In the case of the vacuum circuit breaker, the failure was considerably less violent.

Answers for infrastructure.

The vacuum interrupters were replaced, and the arc by-products (soot) cleaned from both the circuit breaker and the compartment. The unit was put back into service.

Our test experience in the laboratory, where we routinely explore the limits of interrupter performance, also supports these results.

More recently, several tests were performed in our high-power test laboratory to compare the results of attempted interruptions with "leaky" vacuum interrupters. A small hole (approximately 1/8" diameter) was drilled in the interrupter housing, to simulate a vacuum interrupter that had lost vacuum. The results of these tests were very interesting:

1. One pole of a vacuum circuit breaker was subjected to an attempted interruption of 1,310 A (rated continuous current = 1,250 A). The current was allowed to flow in the "failed" interrupter for 2.06 seconds, at which point the laboratory breaker interrupted. No parts of the "failed" circuit breaker or the interrupter flew off, nor did the circuit breaker explode. The paint on the exterior of the interrupter arcing chamber peeled off. The reaminder of the circuit breaker was undamaged.
2. A second pole of the same vacuum circuit breaker was subjected to an attempted interruption of 25 kA (rated interrupting current = 25 kA), for an arc duration of 0.60 seconds, with the laboratory breaker interrupting the current at the time. The arc burned a hole in the side of the arc chamber. The circuit breaker did not explode, nor did parts of the circuit breaker fly off. Glowing particles were ejected from the hole in the arcing chamber. None of the mechanical components or other interrupters were damaged. Essentially, all damage was confined to the failed interrupter.

Our experience suggests rather strongly that the effects of a vacuum interrupter failure on the equipment are very minor, compared to the impact of failures with alternative interruption technologies. But the real question is not what the results of a failure might be, but rather, what is the likelihood of a failure?

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

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 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 both the contact and the interrupter end plate, the failure rate of this moving connection is extremely low. This accounts for the extremely high reliability of Siemens vacuum interrupters today.

In fact, the MTTF (mean time to failure) of Siemens power vacuum interrupters has now reached 57,000 years (as of 2010).

Questions raised by customers regarding loss of vacuum were legitimate concerns in the 1960s, when the use of vacuum interrupters for power applications was in its infancy. At that time, vacuum interrupters suffered from frequent leaks, and surges were a problem. There was only one firm that offered vacuum circuit breakers then, and reports suggest that they had many problems.

We entered the vacuum circuit breaker market in 1974, using Allis-Chalmers' technology and copper-bismuth contact materials. In the early 1980s, after becoming part of the worldwide Siemens organization, we were able to convert our vacuum designs to use Siemens vacuum interrupters, which had been introduced in Europe in the mid-1970s. Thus, when we adopted the Siemens vacuum interrupters in the U.S., they already had a very well established field performance record.

The principle conceptual differences in the modern Siemens vacuum interrupters from the early 1960s designs lies in contact material and process control. Surge phenomena are more difficult to deal with when copper-bismuth contacts are used than with today's chrome-copper contacts. Similarly, leaks were harder to control with vacuum interrupters built largely by hand than with today's units. Today, great attention is paid to process control and elimination of the human factor (variability) in manufacture.

The result is that the Siemens vacuum interrupters today can be expected to have a long service life and to impose dielectric stress on load equipment that is not significantly different from the stresses associated with traditional air magnetic or oil circuit breakers.

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