NERC

NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Lesson Learned

Cold Weather Operation of SF_6 Circuit Breakers

Primary Interest Groups

Transmission Owners (TOs)
Transmission Operators (TOPs)
Generator Owners (GOs)
Generator Operators (GOPs)
Reliability Coordinators (RCs)

Problem Statement

When a SF_6 circuit breaker (CB) hits its critical low pressure, its fault interrupting capability can be compromised. Most TOs protect against this by either auto-opening the CB prior to reaching the critical low-pressure level or by blocking the CB from tripping (when it reaches the critical low-pressure level) and relying on adjacent CBs to open in the event of a fault (breaker failure mode). If this occurs across multiple locations, it can place the Bulk Electric System (BES) at additional risk since it weakens the overall topology of the system and can result in more facilities being removed from service to clear a fault. It also means that the contingencies modeled and studied in real-time contingency analysis (RTCA) studies may no longer be accurate, thereby potentially putting the BES in a less secure or unknown state. That condition occurred during the severe cold weather event that hit the upper Midwest region of North America on January 29–30, 2019.

Details

At the 2019 Minnesota Power Conference held November 12–14, 2019, a presentation was given on the operation of SF_6 CBs under low SF_6 pressure conditions caused by severe ambient cold weather conditions. This conference session focused on the SF_6 breaker operations that occurred on two upper Midwest utilities' systems during the severe cold weather event that hit the upper Midwest region of North America January 29–30, 2019. A Regional Protective Relay Subgroup took up this topic at their, meeting, where it became clear that additional TOs within that Area were also impacted by the cold weather event due to reaching critical low-pressure levels on their BES CBs. The Protective Relay Subgroup agreed to explore this issue further to provide more understanding and situational awareness on this topic.

Discussion of SF_6 and Mixed Gas Circuit Breaker Technology

Gas insulated CBs must maintain a design pressure in order for the breaker to achieve its full fault interrupting capability. When pressure starts to drop in the tank, such as when the gas starts to condense (liquefy) due to cold ambient temperatures, it may eventually reach two alarm levels.

The first alarm is a low-pressure alarm that serves as a warning that SF_6 gas density has decreased approximately half way to the lockout pressure. This alarm level allows the entity time to perform corrective actions prior to the lockout pressure.

The second alarm is the lockout (or critical) pressure alarm. This occurs at the lowest SF_6 gas pressure at which the original equipment manufacturer has designed the CB to achieve its rated interrupting capability corresponding to the SF_6 gas density based on ambient temperature. Tripping operations below this level may not successfully interrupt rated fault current and may damage the CB. At this level, a protection scheme is typically installed to either auto-open the CB or block the trip and rely on a breaker failure relay to open all adjacent (or remote) breakers in the event of a fault.

When installed, tank heaters warm the SF_6 inside the CB, raising it above the ambient temperature and the temperature where it may start to condense. During severe cold weather, ambient temperatures outside of the CB's specified operating range may overwhelm the tank heater's ability to keep the SF_6 in a gaseous state. It is likely this may have occurred during the January 29–30, 2019, event in the upper Midwest; 13 of the 81 CBs that hit their critical lockout pressure during that two-day event had heaters that were confirmed to be working. Additionally, there were high winds throughout the Midwest on January 29, 2019, and the effectiveness of the heaters was likely compromised due to these high winds.[1]

Mixed Gas CBs

For areas that can be regularly subjected to temperatures in the -30° to -40° F range or colder, a mixed gas approach is usually used. Mixed-gas CBs were developed for use at temperatures as low as -50° C (-58° F). These breakers utilize a gas mixture of SF_6 and CF_4 or SF_6 and N_2 to prevent condensation of the SF_6 gas. Today's mixed-gas CBs offer excellent cold weather performance and provide the reliability needed for even the most severe cold weather conditions. This is achieved without the use of heaters. Mixed gas CBs used for severe cold weather are predominantly live tank design vs. dead tank design (which can accommodate tank heaters, so a mixed gas is not needed).[2] Canadian utilities within that area predominantly use mixed gas live tank CBs on their bulk power system and they performed without issue during the severe cold of January 29-30, 2020. **Figure 1** illustrates how a mixture of SF_6 and CF_4 remains gaseous at much lower temperatures than pure SF_6 gas.

[1] Wind turbines throughout the upper Midwest were hitting their cold weather cutout limits (typically -30° C (-22° F) as well, causing wind plants to shut down during high output (Refer to LL20200601, "Unanticipated Wind Generation Cutoffs during a Cold Weather Event").

[2] There are two main categories of CBs: one in which the enclosure for the extinguishing medium and the contacts is metallic and grounded, and the other in which the chamber containing the extinguishing medium and contacts is insulated from ground. The former is commonly referred to as a dead tank design and the latter as a live tank design.

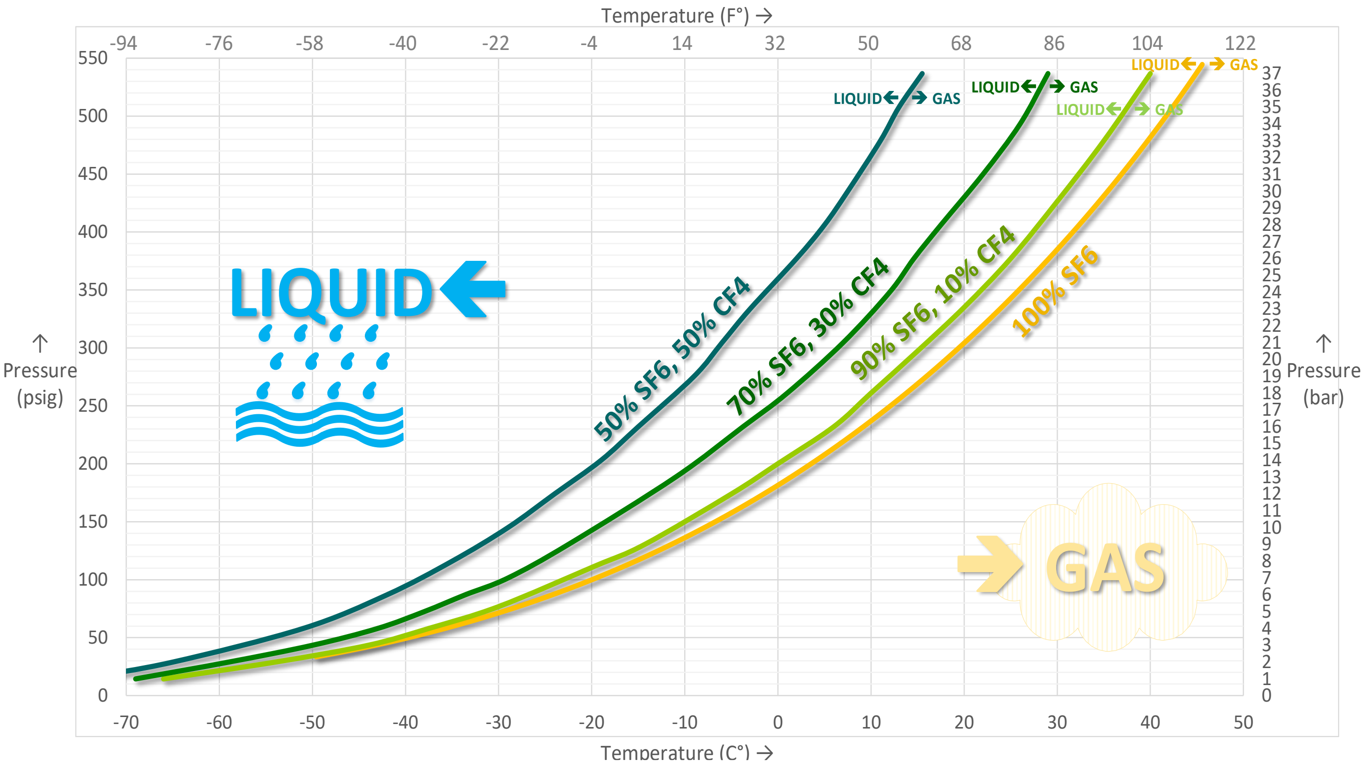

Figure 1: SF_6 and SF_6-CF_4 Mixed Gas Phase Change Diagram

Regional Data Query for CB Operations Due to Critical Low Pressure

Since there was no formal event analysis report for this cold weather event, Regional staff sent a data query to the TOs/TOPs within the event area. Information was collected on each company's philosophy of SF_6 breaker protection during critical low pressure conditions. The query also requested information on actual occurrences January 29–30, 2019, regarding SF_6 breakers hitting their critical low pressure alarm level and what opening or blocking actions occurred. The query targeted the northern TOs/TOPs since they experienced temperatures in the -30° to -40° F range. The TOs/TOPs in the southern half of the region experienced moderate ambient temperatures and were mostly unaffected by the January 29–30, 2019, cold weather event.

Summary of Results from the Regional Data Query

Protection scheme philosophy when SF_6 CBs hit critical low pressure (12 entity responses)

- 7 entities rely on breaker failure scheme protection upon hitting critical low pressure
- 3 entities auto-trip the breaker and block the close upon hitting critical low pressure
- 2 entities will auto-trip or rely on breaker failure, depending on location/situation.

Summary of Actual Operations on January 29–30, 2019

- 6 of the 12 entities had no occurrences of BES CBs hitting critical low pressure
- 6 entities had a total of 81 CBs hit critical pressure and block or auto-open
- One CB was mixed gas design (-50° C, no heater); operation was unrelated to cold weather

- 56 of the remaining 80 CBs did not have heaters operating (70%)
  - 13 CBs had heaters working
  - 11 CBs had unknown heater operation
- Prewinter Heater Inspections/Maintenance
  - 3 of the 12 entities indicated they perform heater prewinter inspections
- Ambient temperatures were recorded for 27 of the 81 CBs that hit their critical pressure level. With the exception of two CBs, the temperatures ranged from -8° F to -35° F. Some of these temperatures were estimated after the fact based on historic weather data for that day/hour and for the vicinity of the substation.

Observations and Conclusions

The following are observations of protection scheme philosophy when SF_6 CBs hit critical low pressure:

- Auto-open vs. blocking at critical low pressure both appear to be routinely used schemes.
- RTCA results may be compromised (for CBs that have blocked trips), thereby potentially putting the BES in a less secure or unknown state.

Observations of live tank mixed gas CBs

- Mixed gas CBs perform exceptionally well down to -50° C (-58° F).
- Live tank CBs do not rely on heaters.
- Live tank mixed gas CBs are predominantly used in far northern locations where ambient temperatures can readily reach -50° C.
- Live tank mixed gas CBs may be more costly, requiring freestanding current transformers (CTs).
- Back-fitting a dead tank CB with a live tank CB at an existing substation may be difficult.
- Mixed gas CBs require more equipment to handle mixed gases.

Observations of dead tank SF_6 CBs:

- SF_6 dead tank CBs are very dependent on their tanks heaters to avoid hitting critical low pressure.
- Only 3 members out of 12 (25%) performed inspections on tank heaters prior to winter.
- Only two entities indicated they receive supervisory control and data acquisition (SCADA) alarms for tank heater failures.
- Wind speed can impact the effectiveness of the tank heaters and wind speed was significant during this cold weather event.

Live tank mixed gas CBs have proven to be very reliable performers down to the extreme cold temperatures that they are designed for (-50° C/-58° F). These types of CBs are predominantly used in far northern locations where ambient temperatures can readily reach -50° C. Mixed gas technology is key to preventing condensation within the breaker tank during severe low temperature conditions. This makes these breakers more reliable since there is no reliance on tank heaters, which may fail (an additional failure mechanism beside gas issues).

Dead tank SF_6 CBs are predominantly used by the members of the region within the U.S. with the exception of remaining oil tank CBs that are still in service. In the southern half of the region, SF_6 CBs perform very well for the cold weather conditions that the southern portion of the region can experience. However, the northern portion relies on tank heaters to maintain SF_6 pressure in their CBs during severe cold ambient temperatures. As can be seen from the query results, 56 CBs (70%) of the SF_6 CBs that auto-opened or blocked their trip January 29–30, 2019, had inoperable tank heaters. Another 11 heaters had unknown status. This is a key disadvantage of using dead tank SF_6 CBs in cold weather climes: reliance of external tank heaters to maintain SF_6 tank pressure to assure sufficient interrupting capability during a fault condition.

Lesson Learned

- Some breakers have internal heaters and integral thermal insulation as part of their design. Others may use external heaters and temporary insulation. The maintenance and inspection of SF_6 CB tank heaters and installation of any associated temporary thermal insulation (blankets) prior to winter season is important to ensure the heaters will be effective going into the winter season.
- Alarming for a tank heater failure can alert operations staff in advance that a CB may hit critical low pressure such that a maintenance crew can be scheduled. These are two best practices that several entities have adopted to minimize the risk of having SF_6 CBs block their trip or auto-open during severe cold weather conditions.
- In the event an SF_6 CB reaches critical low pressure and blocks its trip, the TOs/TOPs should assure that the contingency model involving that CB is updated and shared with all impacted TOPs and RCs such that all EMS models will accurately reflect the outage that will occur for fault clearing (breaker failure mode).

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