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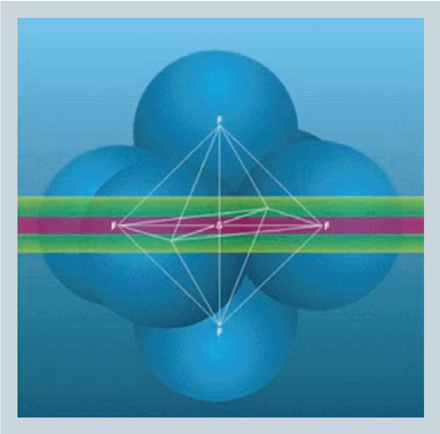
Use of SF_6 gas in medium-voltage switchgear

In this issue, the use of SF_6 (sulfur hexafluoride) gas in medium-voltage switchgear is discussed. SF_6 has been widely used in high-voltage circuit breakers for decades, but its use in medium-voltage equipment is relatively recent. In the medium-voltage arena, Siemens uses SF_6 gas in the load-interrupting switch and switch-disconnector in type SIMOSEC metal-enclosed load-interrupter switchgear rated up to 27.6 kV, and as the insulation medium in gas-insulated vacuum circuit breaker switchgear types 8DA/DB.

Characteristics and properties

A few physical properties of SF_6 include:

- Colorless, odorless, non-toxic and non-flammable
- Inert
- Non-corrosive
- Thermally stable (decomposition does not occur below 500 °C)
- Density approximately five times that of air.



The SF_6 molecule, has six fluorine atoms placed symmetrically around a sulfur atom. The symmetrical arrangement leads to extreme stability, a very desirable characteristic for an insulating gas. This gives the gas a very high dielectric capability, approximately three times the dielectric strength of air at atmospheric pressure. As a result, equipment using SF_6 as an insulating medium can be considerably more compact than equipment using air as the insulating medium.

SF_6 is a highly electronegative gas, an advantage for both dielectric performance and interruption capability. This means that the molecule has a strong electron affinity, so that the gas molecule tends to catch free electrons and build heavily negative ions, which do not move fast. This prevents (or at least retards) the electron avalanche that precedes a flashover.

SF_6 is a "self-healing" dielectric, in that it is largely undamaged by breakdown. This makes it highly suitable as an interrupting medium. The dielectric strength of the gas does not decrease due to decomposition, such as occurs with arcing or arc interruption. It has excellent cooling properties at temperatures associated with arc extinguishing, as the gas uses energy when it dissociates, which provides the significant cooling effect. The process is reversible, so that nearly all of the SF_6 recombines after interruption. Thus, very little of the SF_6 is "used up" during interruption, particularly for interruption of moderate (load) currents.

SF_6 dissociates during arcing into its atomic constituents, one sulfur atom and six fluorine atoms. There are secondary reactions with contacts and insulation exposed to the arc, but such secondary reactions are relatively minor for load current interruptions, increasing in significance when very high currents are interrupted, such as at the full rating of a high-voltage circuit breaker.

While pure SF_6 is odorless, contaminated SF_6 has a pungent or unpleasant odor. The fumes irritate the nose, mouth and eyes. The irritation occurs in seconds, well in advance of any danger from poisoning. As mentioned previously, this degree of contamination of the SF_6 gas would not be expected in a device that switches moderate load currents (e.g., a load interrupter switch or a switch-disconnector), but would be expected in a circuit breaker that interrupts short-circuit currents.

History

SF_6 first became available in the late 1940s in laboratory quantities. Large-scale industrial production began about 1953. By the 1960s, a number of designs of high-voltage SF_6 circuit breakers were available. Predominantly, these were so-called "two-pressure" designs, in which a relatively low pressure was used for insulation purposes, and a high-pressure system was used to interrupt the current. These early units experienced relatively high gas leakage. As the experience with SF_6 in high-voltage circuit breakers grew, the manufacturers introduced "single-pressure" designs and improved sealing techniques, greatly reducing the leakage rate. Today's high-voltage SF_6 circuit breakers have leakage rates below one percent per year.

SF_6 usage

SF_6 has been used extensively in non-electrical applications. Since SF_6 is inert, it is very attractive to the magnesium industry. Magnesium reacts spontaneously in the presence of oxygen, so a heavier-than-air cover gas is used to isolate the molten magnesium from oxygen as the magnesium cools. The aluminum industry has used SF_6 gas in casting operations, to reduce the porosity of cast aluminum parts by exclusion of hydrogen during the manufacturing process. The semiconductor industry uses SF_6 gas in plasma etching and to clean chemical vapor deposition tools. SF_6 has been used, usually together with argon, as a filler gas in thermally-insulated windows.

Finally, in what seems a bizarre use, SF_6 was used for the "gas cushion" in a number of sports footwear products, including some endorsed by widely-known sports personalities.

In electrical equipment, SF_6 is used for nearly all high-voltage (over 38 kV) circuit breakers worldwide. It is also used in gas-insulated substations (GIS) and gas-insulated lines (GIL), highly suited to urban power transmission applications. In the medium-voltage realm (up to 38 kV), SF_6 has been used outside the U.S. for circuit breakers having relatively low interrupting ratings. The market for high interrupting capacity circuit breakers (such as used in metal-clad switchgear) is dominated by vacuum circuit breakers. SF_6 is used extensively worldwide for low switching capacity switches. In these applications, SF_6 allows for extremely compact switching devices, sealed-for-life construction, and very low maintenance.

Environmental issues

In recent years, SF_6 has been widely discussed in the environmental arena. SF_6 is recognized as a very potent greenhouse gas. The U.S. EPA reports that SF_6 has an atmospheric lifetime of around 3,200 years, and a global warming potential (100-year horizon) of 23,900 times that of CO_2. The EPA 2010 report of greenhouse gas inventory (refer http://epa.gov/climatechange/emissions/downloads10/US-GHG-2010_Report.pdf) shows SF_6 emissions associated with electrical transmission and distribution for 2008 as 13.1 $T_gCO_2E_g$ (page 242, table 4-92), a decrease of about 51 percent from emissions in 1990. $T_gCO_2E_g$ is the expression for GWP-weighted emissions for all gases and denotes teragrams (or million metric tons) of CO_2 equivalent. The emissions of 13.1 $T_gCO_2E_g$ was about 0.2 percent of the total 6,956.8 $T_gCO_2E_g$ for all greenhouse gas emissions in the U.S. for 2008 (refer to pages 28-30, table ES-2). A CIGRE working group, WG23.02, studied SF_6 use in the electric industry, and estimated that the electrical emissions of SF_6 gas into the atmosphere accounted for approximately 0.1 percent of the total global warming potential of gases in the atmosphere (as of 1999). By contrast, CO_2 contributes around 60 percent of the total global warming potential in the same time period.

The major reason that the electrical use of SF_6 has such a low impact on global warming is that electrical usage is on the basis of a "closed system." In part due to the cost of the gas, and primarily to reduce environmental impact, the gas is carefully "protected" at all stages during the lifecycle. Processes are controlled during manufacture to assure that gas losses are held to a minimum. The switchgear is designed so that leakage of gas over the life of the switchgear is minimal.

At the end-of-life condition, there are widely available service firms who specialize in recovering used SF_6 gas for shipment to gas reprocessing firms. These service firms also keep up-to-date on the proper handling procedures and regulations for the handling of SF_6 gas and byproducts. Used SF_6 gas can be recovered and reprocessed for reuse. Nearly all of the SF_6 gas in use in electrical equipment will ultimately be recovered and reused.

Significant research has been conducted to find a substitute for SF_6 gas in electrical products. A lengthy report has been issued by National Institute of Standards and Technology (NIST) on potential alternatives to pure SF_6 for insulation and arc interruption, concluding that there is no replacement gas immediately available to use as an SF_6 substitute. Separately, L. Niemeyer studied the issue and concluded that "a functionally equivalent substitute gas for SF_6 does not exist" (L. Niemeyer: "A systematic search for insulation gases and the environmental evaluation," Gaseous Dielectrics VIII, Plenum, NY, 1998). NIST also indicated that there are significant questions concerning the performance of gases other than pure SF_6. In short, it appears that use of SF_6 will continue into the foreseeable future in electrical equipment. At this time, there is no indication that the U.S. EPA will restrict the use of SF_6 in electrical equipment , but requirements for reporting SF_6 inventories and losses will be implemented soon.

SF_6 use in types 8DA/8DB switchgear

Insert new paragraph "Types 8DA/DB medium-voltage, vacuum circuit breaker switchgear use low-pressure SF_6 as an insulating medium for all primary voltage components. Fixed-mounted, vacuum circuit breakers are used for circuit interruption, and the equipment incorporates three-position switches (CLOSED-OPEN-READY-TO-GROUND) for transfer of the feeder circuit from one bus to the other (for double-bus type 8DB), and for isolation in both the double-bus type 8DB and single-bus type 8DA.

Use of SF_6 insulating gas excludes environmental contamination (such as rodents, moisture, dirt, corrosive atmospheres, etc.) so that the primary components do not require periodic maintenance. Due to the high dielectric strength of SF_6 gas, an extremely compact arrangement is possible. Since the circuit breaker is fixed-mounted, maintenance associated with drawout mechanisms is eliminated.

SF_6 use in SIMOSEC switchgear

SF_6 is used in the SIMOSEC switchgear design for the load-interrupting switch and for the switch-disconnector in a variety of configurations. This design takes advantage of the main characteristics of SF_6 and minimizes the environmental issues associated with the gas.

The switch is enclosed in a welded, stainless-steel vessel or enclosure. The enclosure is sealed-for-life, so there is no need to periodically replenish the gas. The switch mechanism itself is maintenance-free, with no need to perform contact alignment, contact adjustment or similar functions. Since the switch is sealed, it is isolated from contaminants in the atmosphere, further prolonging the life of the switch.

The filling pressure of the gas is low, 7.25 psig, and only a small quantity of gas is used. The enclosure is welded and a stainless steel bellows is used to transfer mechanical motion, eliminating the need for sliding or rotating seals and gaskets. The annual leakage rate is below 0.1 percent per year, so no replenishment of the gas is needed over the life of the switchgear.

The switch enclosure is sealed-for-life, so there is no need to provide for periodic maintenance of the gas. A gas density indicator, essentially a "go/no-go" device, is provided, indicating whether the amount of gas in the switch is acceptable or if the switch is "not ready for service." As discussed in the section of this issue relative to "characteristics and properties," the SF_6 gas in the switch is largely free of degradation over the entire life of the switch.

The switch also includes a viewing window or port, so that the position of the switch blades can be visibly verified as required by certain U.S. regulations and codes.

Summary

SF_6 has excellent dielectric properties, and is well suited for use in interrupting devices for relatively low switching ratings, such as for load interrupter switches as used in the type SIMOSEC switchgear line. Its use in gas-insulated, medium-voltage vacuum circuit breaker types 8DA/DB switchgear allows for extremely compact switchgear since the gas is used only for its insulating qualities and interruption takes place in a vacuum. Use of SF_6 reduces the space requirements for the switchgear, isolates the switching elements from environmental contamination, and allows significant reduction of maintenance.

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