

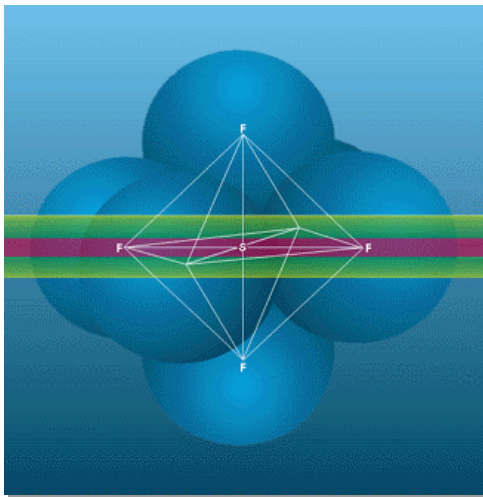
TechTopics Topic: Use of SF₆ Gas in Medium Voltage Switchgear

In this issue, we discuss the use of SF₆ (sulfur hexafluoride) gas in medium voltage switchgear. SF₆ has been widely used in high voltage circuit breakers for decades, but its use in medium voltage is relatively recent. In the medium voltage arena, Siemens uses SF₆ gas in the load interrupting switch and switch-disconnector in SIMOSEC metal-enclosed load interrupter switchgear rated up to 27.6kV.

Characteristics and Properties:

A few physical properties of SF₆ include:

- Colorless, odorless, non-toxic, and non-flammable
- Inert
- Non-corrosive
- Thermally stable (decomposition does not occur below 500 °C)
- Density approximately 5 times that of air



The SF₆ molecule, shown at the left, 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 SF₆ as an insulating medium can be considerably more compact than equipment using air as the insulating medium.

SF₆ 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) electron avalanche that precedes a flashover.

SF₆ 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 SF₆ recombines after interruption. Thus, very little of the SF₆ is “used up” during interruption, particularly for interruption of moderate (load) currents.

SF₆ 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 SF₆ is odorless, contaminated SF₆ 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 SF₆ 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:

SF₆ 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 SF₆ 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 SF₆ 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 SF₆ circuit breakers have leakage rates below 1% per year.

SF₆ Usage:

SF₆ has been used extensively in non-electrical applications. Since SF₆ 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 SF₆ gas in casting operations, to reduce the porosity of cast aluminum parts by exclusion of hydrogen during the manufacturing process. The semiconductor industry uses SF₆ gas in plasma etching and to clean chemical vapor deposition tools. SF₆ has been used, usually together with argon, as a filler gas in thermally-insulated windows. Finally, in what seems a bizarre use, SF₆ was used for the “gas cushion” in a number of sports footwear products, including some endorsed by widely-known sports figures.

In electrical equipment, SF₆ is used for nearly all high voltage (over 38kV) 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 38kV), SF₆ has been used outside the US 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. SF₆ is used extensively worldwide for low switching capacity switches. In these applications, SF₆ allows for extremely compact switching devices, sealed-for-life construction, and very low maintenance.

Environmental Issues:

In recent years, SF₆ has been widely discussed in the environmental arena. SF₆ is recognized as a very potent greenhouse gas. The US EPA reports that SF₆ has an atmospheric lifetime of around 3200 years, and a global warming potential (100-year horizon) of 23,900 times that of CO₂. The EPA does not report emissions of SF₆ separately, but instead reports a group of gases, including hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and SF₆. The emissions of HFCs, PFCs, and SF₆ for 2000 are shown in the EPA report as having 2% of the global warming potential of all greenhouse gas emissions. A CIGRE working group WG23.02 studied SF₆ use in the electric industry, and estimated that the electrical emissions of SF₆ gas into the atmosphere accounted for approximately 0.1% of the total global warming potential of gases in the atmosphere (as of 1999). By contrast, CO₂ contributes around 60% of the total global warming potential in the same time period.

The major reason that the electrical use of SF₆ 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 SF₆ 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 SF₆ gas and byproducts. Used SF₆ gas can be recovered and reprocessed for reuse. Nearly all of the SF₆ gas in use in electrical equipment will ultimately be recovered and reused.

Significant research has been conducted to find a substitute for SF₆ gas in electrical products. A lengthy report has been issued by NIST on potential alternatives to pure SF₆ for insulation and arc interruption, concluding that there is no replacement gas immediately available to use as an SF₆ substitute. Separately, L. Niemeyer studied the issue and concluded that “a functionally equivalent substitute gas for SF₆ 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 SF₆. In short, it appears that use of SF₆ will continue into the foreseeable future in electrical equipment. At this time, there is no indication that the US EPA will restrict the use of SF₆ in electrical equipment.

SF₆ Use in SIMOSEC Switchgear:

SF₆ 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 SF₆ 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 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% 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 SF₆ 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 US regulations and codes.

Summary:

SF₆ 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 SIMOSEC switchgear line. Use of SF₆ reduces the space requirements for the switchgear, isolates the switching elements from environmental contamination, and allows significant reduction of maintenance.

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