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Medium-Voltage Gas-Insulated Switchgear (MV GIS) using Alternative Gases

Ms. Bylin,

November 2017 the California Air Resource Board (CARB) presented its 2017 Climate Change Scoping Plan[1]. The strategy for achieving California's 2030 greenhouse gas (GHG) target builds on the State's successes to date, proposing to strengthen major programs that have been a hallmark of success, while further integrating efforts to reduce both GHGs and air pollution. California's climate efforts is along the same trajectory like other institutions, working on lowering the impact of GHG emissions.

Sulfur hexafluoride (SF_6) is the man-made gas with the highest potential to contribute to global warming if released to the atmosphere. Its global warming potential (GWP, over a 100-year period, expressed in CO_2 equivalent) ranges between 22,800 and 23,900, dependent on the source wherefrom the number is taken, and it is regulated under the Kyoto Protocol.

Worldwide measures show that SF_6 concentration in the atmosphere by all kind of SF_6 emissions is on a low level (a few parts per trillion) but constantly rising. So, it is the right time that all SF_6 applicants shall look for viable, sustainable alternatives. This includes the electrical industry, although its reported contribution to global warming by SF_6 is in the range 0.05% in relation to all GHG CO_2 equivalent emissions. Reported data show that this situation expressed in shares in the U.S.[2] is pretty similar to Europe (EU-28)[3].

Sulfur hexafluoride is a commonly applied substance in electricity transmission and distribution (T&D) equipment, primarily for insulation and arc quenching in medium-voltage and high-voltage equipment. While SF_6 application in high-voltage electrical equipment just started in the 1960's, by the end of the 1960's its application was widespread in high-voltage switchgear and circuit-breakers. SF_6 application in medium-voltage equipment followed two decades later in the 1980's.
Today, medium-voltage equipment most commonly applying SF_6 include switching devices (circuit-breakers, load-break switches, disconnectors) and switchgear where those devices are installed. But SF_6 also is used during the manufacturing of other equipment installed in medium-voltage switchgear, such as instrument transformers.

Over decades SF_6 gas-insulated switching devices and switchgear have proven its contribution to a reliable and stable power network as well as ensuring high personnel safety during operation. It goes along with minimizing power transmission losses and conserving resources since the SF_6 technology led to compact, footprint optimized switchgear designs.
SF_6's widespread use in the electrical sector for the last several decades is also due to a unique range of outstanding electrical and chemical properties.

[1] https://ww3.arb.ca.gov/cc/scopingplan/scopingplan.htm
[2] U.S. Inventory of GHG Emissions and Sinks: 1990-2017
[3] Annual European Union greenhouse gas inventory 1990-2016 and inventory report 2018; Annex V

Nevertheless, due to its high global warming potential (GWP), the CARB adopted a Regulation in 2010 for reducing SF_6 emissions from gas-insulated electrical switchgear which requires electrical switchgear owners to reduce their emission rates, reaching a 1 percent emission rate by 2020.

While minor emissions of SF_6 from gas-insulated electrical equipment is possible through seals, during equipment installation and when equipment is opened for servicing, almost all medium-voltage equipment has always been of sealed pressure system type, for which the International Electrotechnical Commission supplies a clear definition not requiring any gas work during equipment's entire operating time ("sealed for life"). An upper leakage rate limit for sealed pressure systems is stated to 0.1 percent by the associated IEC Standard[4] while state-of-the-art sealed medium-voltage equipment offers leakage rates significantly below this limit.

Nevertheless, as alternative substances for electrical insulation with lower GWP emerge, CARB staff are proposing to amend the current regulation to further reduce GHG emissions. As a pioneer and driver of sustainability Siemens fully supports CARB's strategy for sustainable development, focused on climate change and clean energy[5]:

- "We develop our products, solutions and services using a life cycle perspective and sound eco-design standards."
- "We minimize the environmental impact of our operations through environmental management programs, and we aim to become carbon-neutral by 2030."
- "We help our customers increase energy efficiency, save resources and reduce carbon emissions."

Electrical equipment manufacturers have been working successfully for years to reduce SF_6 emissions in their products and to research for alternatives. Technology trends for electrical switchgear without SF_6 have been around for many years, but now a market trend towards SF_6 alternatives is beginning to establish itself "tenderly", still only in selected applications and submarkets.
Products and pilot installations with alternative extinguishing and insulating gases are already available, even those avoiding fluorinated gases and using vacuum interrupters as the technical optima. All those still serve limited applications in medium-voltage distribution networks and in the lower voltage segment of the high-voltage transmission system.

SF_6 alternatives must fulfil specific requirements: Long-term stability must preserve operator's CAPEX and OPEX and the CO_2 equivalent reduction must be assured over lifetime to be real environmentally friendly. Alternatives must also respond to the following questions:

- Shall SF_6 alternatives contain F-gases?
  If yes, shall equal reporting requirements apply as for SF_6?
- Which technical performance restrictions are acceptable?
- Which EHS drawbacks offset GWP reduction?
- Are handling and process modifications riskless?
- Socio economic impact?
- Upgrading of Standards – gas handling, GIE standards

Some of these questions are currently addressed by international activities at Study Committees of the International Council on Large Electric Systems (CIGRE)[6]. Some results will be available next, others shall be available in the years to come. At IEC an ad hoc working group has identified the set of international Standards that will have to be adapted to cover alternative gases or gas mixtures to SF_6 in electrical equipment. Today an IEC Maintenance Team only addresses IEC 62271-4 edition 2.0 "High-voltage switchgear and controlgear - Handling procedures for SF_6 and its mixtures" with a targeted publication of the revised Standard by September 2022[7].

[4] refer to IEC 62271-1:2017 § 3.6.6.3, § 6.16.4

[5] Siemens AG, Sustainability Information 2017

[6] https://www.cigre.org/

[7] Refer to https://webstore.iec.ch/publication/6739

A range of alternative gases and gas mixtures for medium-voltage applications are promoted on the market in hopes of meeting demand for a full SF6 substitute. Those include natural origin gases (N_2, O_2, CO_2) and its mixtures and gas mixtures based on partially new developed other F-gases (e.g. Fluoronitrile, Fluoroketone) targeting to meet, or at least coming close to SF_6's unique technical performance, i.e. among others dielectric behavior, switching and short-circuit capabilities, heat transfer, chemical stability incl. recombination ability. All of those while keeping today's SF_6 physical switchgear footprint.

Beside the technical performance of alternative gases and gas mixtures specific attention must be turned to environmental, health and safety (EHS) topics. An indication is given by the alternative substances manufacturer's Safety Data Sheets where the latest findings of applied pure substance research is recorded in revolving document issues. Although data might be available for amount of substance used today, data are missing for amount of substance to fully cover a wide application in industry.
In addition, end-of-life treatment of those substances and its mixtures applied in electrical equipment must be observed just as its alteration during the switchgear equipment's operation by electrical and chemical effects. Those relate e.g. to switching, ordinary or abnormal partial discharge and may produce by-products with anomalous EHS effects or influence the alternative gases' and gas mixtures' overall performance.

CARB's discussion draft of "Potential Changes to the Regulation for Reducing Sulfur Hexafluoride Emissions from Gas Insulated Switchgear", dated August 15, 2019, Subchapter 10: Climate Change,
Article 4: Regulations to Achieve Greenhouse Gas Emission Reductions, Subarticle 3.1: Regulation for Reducing Greenhouse Gas Emissions from Gas Insulated Equipment provides under § 95352: Sulfur Hexafluoride Phase Out, Table 1 and Table 2, include fixed phase-out dates when owners of medium-voltage SF_6 gas-insulated equipment may no longer acquire this kind of equipment.
Considering the fact that significant product development and gaining long-term experience in operation is still required, along with cost-intensive, complex, time-consuming overall industrialization of a comprehensive SF_6-free portfolio in order to cover the full range of today's SF_6 gas-insulated medium-voltage products and systems, a fixed phase-out date seems not to be appropriate.

It bears the risk that non-sustainable alternatives are forced into operation while important and essential EHS topics are still not exclusively answered.
CARB should allow frequent review of technological development in the area of medium-voltage electrical T&D equipment via piloting rather than providing fixed SF_6 equipment phase-out dates and making alignment with other international initiatives via best practice sharing.

The Siemens approach

Siemens is convinced about a new core technology for GIS SF_6 alternatives in the market. This leading technology is vacuum technology for switching, which opens further applications
- in high-voltage power transmission equipment, and
- for a large amount of load-switching equipment in the medium-voltage power distribution level.

A new technological chapter is opened. Vacuum interrupter technology as a switching principle overcomes limitations of SF_6 gas switching technology and leaves "only" the dielectric insulation as a challenge. It is thus the enabler for a new degree of freedom in choosing insulating gases ensuring a consistent performance over lifetime.

In the area of electrical power transmission and distribution equipment, only an approach with natural origin gases based on the components of ambient air, avoiding use of all kind of fluorinated gases, is perceived as a real sustainable approach.

Siemens blue GIS is based on three conclusive pillars:

- Relying on well-proven and highly reliable vacuum interrupter technology for switching purposes.
- Using natural origin gases based on the components of ambient air ("Clean Air") for dielectric insulation within the equipment which is environmentally friendly since it comprises no artificial F-gases or chemical additives.
- Keeping all benefits known for decades from matured, high-technology SF_6 gas-insulated switchgear.

Conclusion:

Electrical equipment manufacturers have been working for years to reduce SF_6 emissions in their products and researching for alternatives. Products and pilot installations with alternative extinguishing and insulating gases and gas mixtures are already available, even those avoiding fluorinated gases and using vacuum interrupters as the technical optima.
Those still serve limited applications in medium-voltage distribution networks and in the lower segment of the high-voltage transmission system. To cover the full range of SF_6 insulated products and systems, significant product development and gaining long-term experience in operation is required.

Effective and economic support for the development and market introduction should be the goal for ordinary applications of new medium-voltage SF_6-free technologies from 2030 onwards. Economic concerns for manufacturers and operators must be considered, particularly since clear market signals are currently missing for a complete, cost-intensive, complex, time-consuming overall industrialization of a portfolio and for a further portfolio development application by application.

Clear distinction shall be made between medium-voltage sealed pressure system equipment versus high-voltage closed pressure system equipment. The International Electrotechnical Commission supplies a clear definition of those pressure systems which shall be applicable worldwide to avoid any disarray[8].

Special attention shall be turned to EHS topics and the socio-economic impact of promoted alternatives. Newly developed F-gases and its by-products leave questions open concerning its toxicity and remaining risks concerning carcinogenetic and mutagenic impact.

CARB should allow frequent review of technological development in the area of medium-voltage electrical T&D equipment via piloting rather than fixed SF_6 equipment phase-out dates.

Chronological adjustment with standardization activities which describe application, design and performance criteria and handling of alternative gases or gas mixtures in electrical equipment shall be considered. Other regional and international initiatives e.g. European F-Gas regulation[9], European Manufacturers and grid operators self-commitment, CIGRE Study Committees and IEC Standardization shall be reviewed for best practice sharing.

[8] Also refer to CARB definition in document: Discussion draft of "Potential Changes to the Regulation for Reducing Sulfur Hexafluoride Emissions from Gas Insulated Switchgear", dated August 15, 2019, Subchapter 10: Climate Change, Article 4: Regulations to Achieve Greenhouse Gas Emission Reductions, Subarticle 3.1: Regulation for Reducing Greenhouse Gas Emissions from Gas Insulated Equipment, provided under § 95351: Definitions and Acronyms

[9] Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases

Siemens thinks that replacing fluorine compounds by natural origin gases is reasonable and constitutes a real sustainable approach. The technical feasibility of this F-gas free approach is demonstrated in selected applications and opens further opportunities, nevertheless it is still a demanding and a long-term challenge to cover most applications known from SF_6 technology.

Thanking you,

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