IMPROVING THE BOTTOM LINE: HOW GAS-INSULATED SUBSTATIONS CAN OFFER OPERATIONAL & MAINTENANCE COST SAVINGS FOR PETROCHEMICAL FACILITIES

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Abstract – To avoid production downtime, petrochemical facilities need reliable infrastructure. Gas-insulated switchgear (GIS) can often offer counterintuitive cost-effective solutions for petrochemical facilities that are considering new substation construction or upgrades to existing substations. Obstacles such as higher initial capital investment, lack of GIS operation and maintenance expertise, and sulfur hexafluoride gas (SF_6) emissions concerns can prevent facilities from pursuing this option despite potential long-term savings. This paper offers solutions to these common roadblocks and presents several benefits that positively impact a facility's bottom line. The paper explores long-term maintenance costs for GIS substations versus air-insulated substations; the lower costs of depreciation over a GIS substation's longer useful life; and the greater reliability of GIS substations. Additional considerations that can impact operational and maintenance costs include reduced safety risks for personnel and enhanced equipment protection in high contamination environments. Installing modular GIS assemblies can also reduce construction time, minimizing potential disruptions to plant operations. Additionally, the historically predominant SF_6 gas insulating medium, whose use is rapidly becoming more heavily regulated due to its environmental impact, is no longer the only option for GIS builds. New alternative insulation gas mixtures can eliminate the use of SF_6 gas, helping facilities meet environmental sustainability goals.

Index Terms — Substation Reliability, Gas-Insulated Switchgear (GIS), Air-Insulated Switchgear (AIS)

I. INTRODUCTION: WHAT IS GIS?

Conventional substations, also known as air-insulated substations (AIS), use atmospheric air as a dielectric gas medium. However, AIS design is not the only approach to substation design and construction. A gas-insulated switchgear (GIS) substation is a type of high voltage electrical facility whose major conducting structures – e.g., high voltage conductors, voltage transformers, switches, circuit breaker interrupters, current transformers – are protected from outside elements within an enclosure using a pressurized dielectric gas as an insulating medium.

Air-insulated switchgear consists of components built on foundations with significant space between elements to achieve sufficient electrical clearance via air. Gas-insulated switchgear is much more compact since its components are housed within gas-tight aluminum enclosures (see Fig. 1). The GIS applications discussed in this paper are typically used for voltages of 69kV and above.

Fig. 1 GIS Equipment

GIS is a well-established technology that can meet certain challenges more effectively than AIS. As a result, GIS has found significant traction in many parts of the world and is gaining increased consideration in North America, specifically for its ability to mitigate space limitations, strengthen safety and security, lower operational and total lifecycle costs, and enhance overall substation reliability. Indeed, GIS stands out for its ability to resolve several disadvantages or challenges inherent in AIS structures, including:

- Rapid equipment deterioration due to environmental exposure,
- Frequent maintenance requirements,
- Large footprint requirements, which can be difficult to accommodate in facilities where space is limited, and
- Security vulnerabilities.

How GIS works:

- Electrical high voltage conductors are housed within a metal enclosure (see Fig. 2).

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- Electrical clearance between live parts (e.g., bus bars, breakers, and switches) and an earthed enclosure is achieved by an insulating gas (historically SF_6, though alternatives are now available). The insulating gas allows much smaller arrangements due to its higher electrical field stress withstand capability.
- The insulating gas is self-healing after being exposed to electrical arcs.

Typically, GIS equipment is modular and bolted together with flanged connections which allow manufacturers to build switchgear from a finite number of subcomponents and allows the equipment to be expandable. Electrical insulation is achieved by inserting an insulating medium into the space (insulation gap) between the electrically charged current conductor and solidly earthed enclosure (see Fig. 2). As the high voltage stress becomes stronger, the better the withstand capability of the insulating medium must be. See Figs. 3 and 4 for section views of single-phase and 3-phase GIS substation examples.

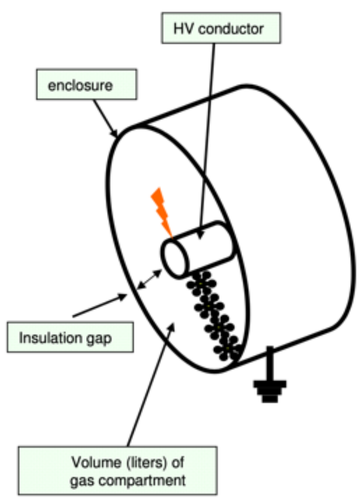

Fig. 2 How Electrical Insulation Is Achieved in a Gas-Insulated Switchgear

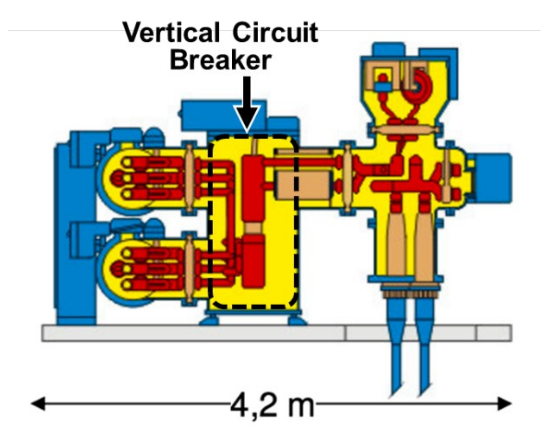

Fig. 3 Example Interior Cross-Section of 3-Phase Enclosed GIS (170kV)

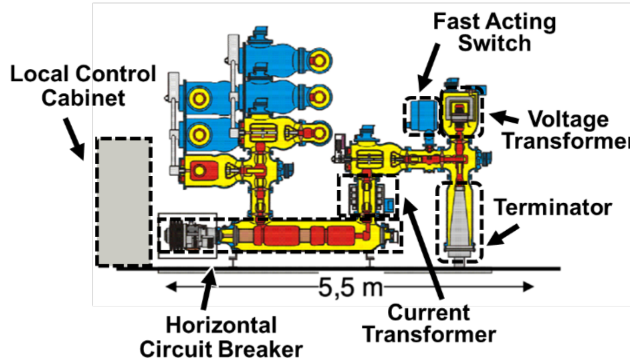

Fig. 4 Example Interior Cross-Section of 1-Phase Enclosed GIS (300kV)

The requirements for the conventional open-air, metal-clad approach can create challenges for designers, operators, and utilities. For example, the phase-to-phase and phase-to-ground clearances in AIS substations are typically 5 to 10 times those required for GIS substations with equivalent ratings, requiring yards with a significantly larger footprint than equivalently-rated GIS, with all live parts completely exposed to the environment and personnel.

By contrast, clearance space required for a GIS substation is only around 10% to 20% of what is needed for an AIS substation (see Figs. 5 and 6 below; for more information on this point, see Section III-E).

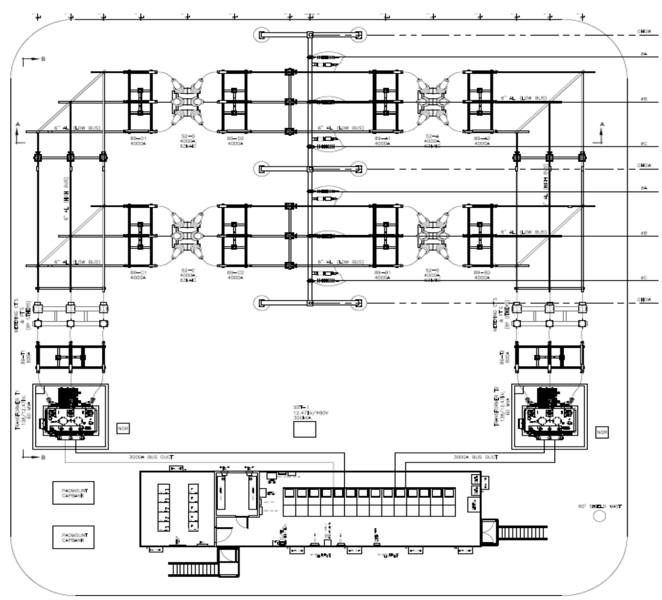

Fig. 5 General AIS Layout – 138kV 4 Breaker Ring (60.96 m by 74.68 m)

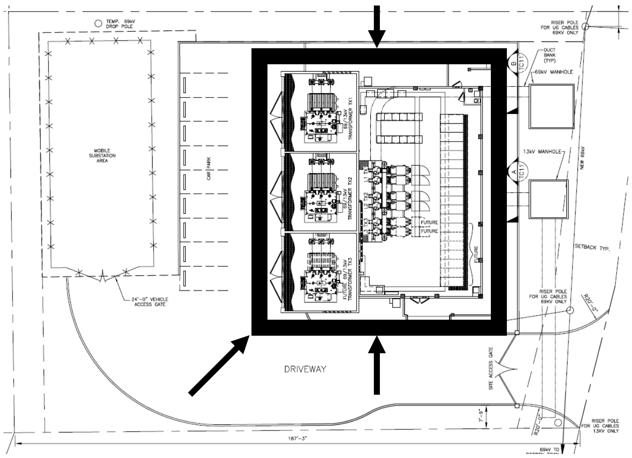

Fig. 6 GIS Layout – 138kV 4 Breaker Ring; GIS Building in Black Box (24.38 m by 22.86 m); Overall Site (42.67 m by 64.62 m)

Further, because GIS substations are typically placed within enclosed buildings that are protected from environmental conditions and people, they offer enhanced equipment protection. That protection can be especially significant for industrial/petrochemical manufacturing facilities that must contend with high contamination environments affected by released gases and, in coastal areas, exposure to salinity. In other words, the outdoor AIS solution is far more vulnerable to harsh environments than GIS. The result is higher operation and maintenance (O&M) costs and shorter expected lifetimes for AIS equipment.

In terms of performance (up to 1,100kV), the service voltage, continuous current, and interrupting ratings for air- and gas-insulated switchgear are comparable. Switching of high nominal currents (above 3000A) and interruption of fault currents greater than 40kA is possible within very small geometries using SF_6 or similar gases as arc-quenching media. Though GIS works well within a range of applications, it is particularly suited to 34.5kV and above and is available for short circuit current ratings from 40kA and above.

Altogether, a smaller footprint, reduced maintenance requirements, and lower cost of operation mean GIS offers significant short- and long-term cost savings, as will be detailed in this paper.

TABLE I
AIS ADVANTAGES AND DISADVANTAGES

AIS ADVANTAGES
• Lowest upfront capital expenditure for equipment and installation.
• Tried and true technology adopted by all utilities, with numerous equipment options on the market.
• Can be installed and maintained by any electrical contractor or service group.
• Equipment (breakers/switches) can be replaced if failures occur.
• Standardized AIS substation designs and solutions available.
AIS DISADVANTAGES
• Requires largest footprint of all solutions (cost of land acquisition and permitting issues should be considered for total overall cost of ownership).
• Most expensive O&M costs throughout lifecycle with regular maintenance required.
• Lower reliability over lifecycle, leading to more planned and unplanned outages as equipment ages.
• Exposed to the environment / open yard (e.g., susceptible to storms and security breaches)
• Additional safety considerations (e.g., exposed live parts)

TABLE II
GIS ADVANTAGES AND DISADVANTAGES

GIS ADVANTAGES
• Lowest overall cost of ownership throughout lifecycle of substation when considering operating expenditure / land cost / permitting, site prep, etc.
• Up to 85% reduction in substation footprint.
• All live parts enclosed in a grounded enclosure with arc-quenching SF_6.
• Ideal for urban or public settings / occupied buildings / underground.
• Inherently storm-hardened design protected from environment.
• Little maintenance and service required during lifetime.
• Substation security enhanced since GIS substations are typically in enclosed buildings.
GIS DISADVANTAGES
• Higher upfront capital expenditure for equipment and installation compared to AIS.
• Technology still new to some utilities.
• Specialty contractors and training required for installation and operation.
• Gas handling is required during maintenance and repair.
• Before a GIS can be installed, site preparations (for an outdoor GIS) or building assembly (for an indoor GIS) must be complete. A clean and controlled environment is necessary to avoid contaminants within the gas zones.

II. RELIABILITY ANALYSIS OF GIS

Due to their high electric load needs, petrochemical and other industrial facilities require robust electric infrastructure. Reliable power is critical for the continuous operation of these networks: any interruptions in service mean production downtime, missed targets, and delayed customer deliveries.

Analysis suggests that GIS can meet reliability needs better than AIS. GIS delivers this enhanced reliability in several ways.

- The enclosed GIS components arrive on site in modular, factory-assembled pieces rather than requiring full field assembly. Pre-fabrication results in fewer parts and interfaces between components to handle and maintain.
- The enclosure also protects against environmental damage and deterioration that can affect performance and reliability.
- GIS has lower lifetime maintenance requirements, with an estimated lifecycle of 40–50 years and only minimal time- and operation-based maintenance required (see Section III for more information about maintenance requirements).
- Performance and maintenance monitoring of GIS substations is typically far more advanced than AIS, reducing the number of site activities and interventions (e.g., diagnostic checks can be conducted in advance).

On the last point, similar advanced diagnostics are also available with AIS, but they are optional, and end users frequently opt out of these features due to upfront cost. With GIS, however, monitoring technology is required to assess equipment integrity since visual inspection of internal components is impossible without taking equipment offline. This adds to the initial cost of GIS equipment but, along with these other factors, can result in measurable improvements to substation reliability. Using fault simulation software, substation designers can analyze substation reliability under assorted conditions and determine likely failure rates and outage durations. For instance, in one analysis of comparable busbar configurations, researchers tested single and double busbar configurations on the high voltage side "of [high voltage/medium voltage] substations having air-isolated or gas-insulated switchgears" [1]. They found that GIS technology doubled availability when compared to the AIS solution for certain builds (e.g., double busbar configurations).

TABLE III
GIS VS. AIS OUTAGE FREQUENCY AND DURATION [2]

	GIS Ring Bus	AIS Ring Bus
Outage Frequency Due to Equipment Failure	1 per 56.8 years	1 per 8.5 years
Outage Frequency Due to Maintenance	1 per 15 years	1 per 2.5 years
Total Outage Frequency	1 per 11.9 years	1 per 1.9 years
Average Total Outage Duration	1.04 hours per year	3.5 hours per year

A separate analysis reviewed mean time between failures (MTBF) as a measure of reliability and similarly found that GIS has the lower outage frequency, with as much as 85.45% less total annual downtime than a comparable AIS build (see Table III).

III. COST ANALYSIS OF GIS

GIS typically has a higher initial capital investment. However, evaluating the initial capital investment alone is not sufficient to present a full economic analysis of a GIS project. Consideration of the various factors that affect the project's lifecycle is important, including the cost of primary hardware, O&M and disposal costs, and the cost of failures. Overall, total lifecycle costs of GIS facilities, due to minimal maintenance, greater reliability, and fewer interruptions, are typically much lower than AIS (see Table IV). However, the extent of cost savings can vary according to project stage or element (see Table V). Thus, while the initial outlay for primary equipment will be higher in a GIS project, earthwork, civil work, structures, electrical assembly and erection, and other construction components will be notably lower.

TABLE IV
GIS VS. AIS ESTIMATED LIFECYCLES, 230kV SUBSTATION, NORTHEAST US [3]

	GIS	AIS
Average Life Expectancy	50 years	40 years
Maintenance Inspection Interval by Original Equipment Manufacturer (OEM)	8-10 years	5-7 years
Time-based Overhaul by OEM	20-25 years	15-18 years

TABLE V
GIS VS. AIS TYPICAL APPROXIMATE LIFECYCLE COST COMPARISON BY PROJECT ELEMENT [4]

Life Cycle Cost	**AIS**	**GIS**
Planning and Engineering	100%	80%
Real Estate	100%	40%
Primary Equipment	100%	120%
Secondary Equipment	100%	100%
Earthwork, Civil Work, Structures	100%	60%
Electrical Assembly and Erection	100%	70%
Maintenance	100%	50%
Outage	100%	50%

The improved reliability and reduced costs of GIS yield total lifecycle cost savings compared to an equivalent AIS build. Table VI presents comparative cost data for a proposed 230kV project to be constructed in the Northeast US over the full projected lifecycle of the substation (note that Table VI does not consider depreciation).

TABLE VI
GIS VS. AIS ESTIMATED CUMULATIVE COSTS FOR 230kV SUBSTATION, NORTHEAST US (IN MILLIONS USD) [5]

	GIS			**AIS**			
	O&M Cost 0.50%	Failure Cost 0.15%	Total Cost	O&M Cost 1.75%	Failure Cost 0.75%	Cost To Replace	Total Cost
Initial Install			$10.68				$8.01
Year 0	$0.05	$0.01	$10.75	$0.14	$0.06		$8.21
Year 10	$0.50	$0.20	$11.37	$1.40	$0.60		$10.01
Year 20	$1.07	$0.32	$12.07	$2.80	$1.20		$12.01
Year 30	$1.60	$0.48	$12.76	$4.21	$1.80		$14.02
Year 40	$2.14	$0.64	$13.46	$5.61	$2.40		$16.02
Year 50	$2.67	$0.80	$14.15			$10.01	$26.03
Total	**$14.15**			**$26.03**			

Note: Table does not reflect depreciation.

A. *Reduced Construction Time*

GIS comes fully assembled and tested from the factory, so there is less onsite construction work required, all of which reduces installation and commissioning time. Specifically, pre-fabrication means construction is completed in a controlled environment, regardless of weather or external conditions, with more tools and options to perform precision work faster and at lower cost.

Factory construction can yield significant cost savings. For example, petrochemical facilities and renewable energy developers are seeing cost and schedule advantages from factory-built substations, allowing them to interconnect their projects to the grid faster. Nuclear facilities are realizing benefits from modular construction as well: “off-site modular construction has been estimated to reduce the capital cost of a [small modular reactor] by up to 37.98% compared to a stick-built method” [6].

Pre-constructed modules also save time and money in the field. With AIS projects that use pre-constructed modules, the modules arrive on site, leaving less for contractors to assemble on site. This approach reduces labor and travel expenses and allows the substation to be fully installed in a fraction of the time, reducing the total number of hours required onsite for installation [7]. As with AIS modular installations, GIS projects can realize significant time and cost savings due to their modular design.

Refineries in particular tend to have strict working procedures. In one case, a 69kV substation on the US West Coast needed to reduce the number of modules delivered to the site in order to increase onsite installation efficiency. The solution involved offsite assembly, with the entire GIS pre-assembled as six skids plugged together (see Fig. 7 below) and then shipped to the site to reduce overall construction time. In this case, pre-assembly reduced an estimated 18-week field assembly schedule to six weeks total. The cost of pre-assembly offsite is much less than the cost of assembly onsite.

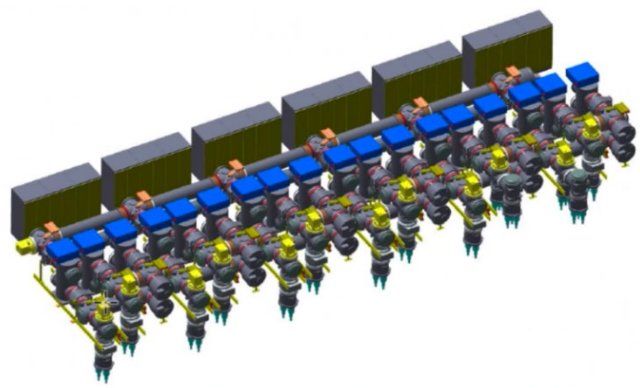

Fig. 7 Pre-Assembled GIS Modules Attached to Six Skids for Delivery to Field

In the same way, GIS can ease installation in difficult, remote, or otherwise hard-to-reach locations, which is often a factor for liquified natural gas (LNG) production facilities. The GIS can be fully prefabricated in a facility nearby or at a supplier near a barging location. Once assembled, operators can simply pull it on a barge to its destination.

B. *Less Downtime, Fewer Disruptions to Plant Operations*

A GIS substation can be built next to an existing AIS substation while continuing to provide power with minimal to no outages. As construction proceeds, the operator can make gradual cutovers from AIS to GIS until the AIS substation is completely offline and can then be removed.

For example, one 500kV substation in Canada (see Fig. 8) had existing AIS infrastructure that was reaching the end of its lifecycle, and the site had no room for expansion. Without GIS, the utility would have had to replace all equipment one-by-one for a new AIS-to-AIS replacement, a process they estimated would have taken ten years. However, thanks to the smaller footprint of a GIS build, they were able to reserve a small portion of land on the other side of the site from the existing AIS substation [8]. The AIS substation remained fully operational while construction proceeded, and construction only required two years to finish. Thus, using GIS supported operational continuity with minimum outages.

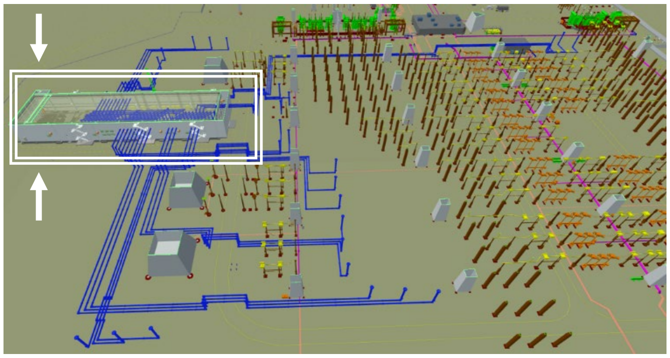

Fig. 8 This 500kV GIS Substation Replaced the Existing 500kV AIS Substation Using a Much Smaller Footprint (GIS Substation in White Box)

C. Less Maintenance, Lower Lifetime Depreciation Costs

Environmental impacts lead to more frequent interventions and shorter life expectancy for AIS substations. Even with a reduced initial cost of only $8 million, AIS failure rates are high enough that costs aggregate much faster than for GIS. Any initial cost savings are subsequently overtaken by these expenses. With all the O&M and failure costs, total lifecycle GIS costs are about half ($14.15 million versus $26.03 million, or 53%) of those for a comparable AIS facility (see Table VI).

A GIS substation contained within protective housing can realize 40–50 years of life with minimal operation costs. In fact, auxiliary components of GIS systems (including disconnect switches, earth switches, etc.) rarely require any maintenance at all (see Table VII). Specialized knowledge is required, but GIS manufacturers typically provide training to equip facility maintenance personnel with the knowledge needed to service GIS equipment.

TABLE VII
BASIC RECOMMENDED MAINTENANCE SCHEDULE FOR GIS

Device	Inspection After	Maintenance After
Overall Installation	8 Years	See Below
Circuit Breaker		20 Fault Clearings or 5,000 Operating Cycles (OC)
Disconnector/ Earthing Switch		5,000 OC
Fast Acting Earthing Switch		2 Closing Operations onto Short Circuit or 2,000 OC

Regarding availability of spare parts – a lack of which could affect mean time to repair (MTTR), undermining the MTBF advantage – established GIS manufacturers have been investing heavily in spare parts manufacturing in order to cope with supply chain challenges, with manufacturer service centers available to provide parts for commissioning and maintenance activities as needed. The number of these centers varies according to manufacturer, but most offer several across North America. Typical GIS warranties extend five to ten years, with additional service contracts available to cover the cost of maintenance and spare parts for the lifetime of the GIS. Under the service level agreements established within these warranties, a response within several hours of failure is typical, with service engineers first performing remote diagnostics before sending out a service technician, if necessary.

Notably, costs related to the insulating gas medium (SF_6 or its alternatives) are comparable. The California Air Resources Board (CARB) reports a "similar level of maintenance [including but not limited to gas purchase, inspection, and repair] for alternative gas technologies and SF_6, hence zero cost difference." [9]

D. Low Failure Rates

GIS is also notable for comparatively low failure rates. A comparative analysis published in the *International Journal of Electrical Engineering & Technology* found that:

> "The rate of failure of disconnecting switch and circuit breaker in GIS is one fourth of that of AIS and one tenth in case of busbar, thus the maintenance cost of GIS becomes less than that of AIS for lifetime. GIS requires less maintenance requirement because of its effective design and protection against external elements…. Whereas in AIS more maintenance is required leading to increase in cost. Operating life of GIS is more than 50 years, and no major inspection is required before 25 years" [10].

The environmental exposure of AIS alone can lead to increased maintenance and outages (see Figs. 9 and 10). In December 2013, a crippling ice storm took one 230kV Canadian substation out of commission, leaving over one million people without power for three days [11]. As a result of that event, a major utility in Canada began converting all their AIS sites into GIS because the latter offered superior protection against severe storms.

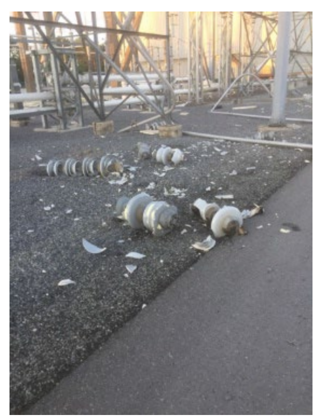

Fig. 9 Example of Storm Damage to AIS Structures Exposed to the Environment

Fig. 10 Example of Storm Damage to AIS Structures Exposed to the Environment

E. *Reduced Footprint*

The footprint of a GIS substation is much smaller than that of an equivalent AIS substation because AIS needs several feet of insulation space while GIS needs only inches. As a result, total area required for GIS is 10% to 20% of AIS [12]. Fig. 11 shows how much space a GIS substation uses on average compared to an AIS substation. In Fig. 12, the GIS switching station depicted delivers as much power as the AIS one while requiring only an eighth of the land for the same configuration.

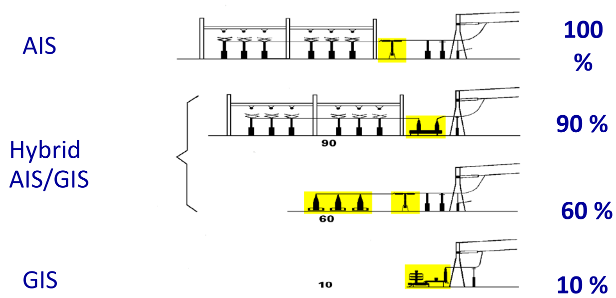

Fig. 11. Comparative Substation Footprints

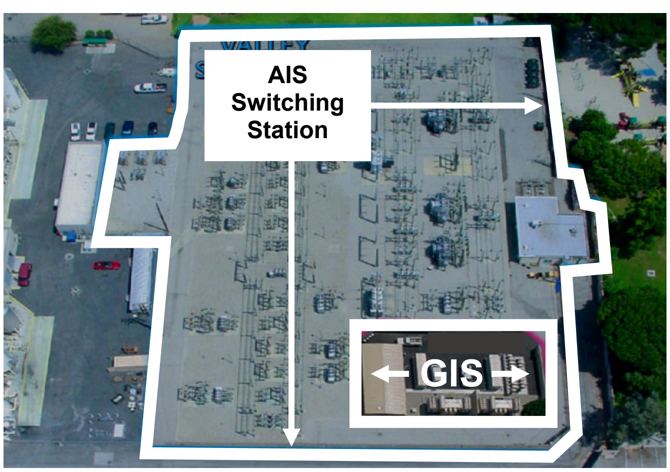

Fig. 12 GIS Switching Station Versus AIS Switching Station

The smaller footprint has multiple implications, most immediately how it reduces site preparation and potentially site acquisition costs [13]. The lower site costs can help offset the upfront higher equipment cost and contribute to long-term savings when less real estate is required to host the substation. In some cases, the reduced footprint even means that GIS substations can be built in areas that are otherwise impossible for locating AIS (e.g., underground sites).

For example, in a first-of-its-kind project, a municipal utility needed a 69/12kV substation constructed in a high property value neighborhood. By using GIS, they were able to place the substation in underground vaults beneath a newly-built park (see Figs. 13 and 14) to meet both growing power demands and maintain neighborhood property values [14].

Fig. 13 Interior of Underground GIS

Fig. 14 Park Above GIS Substation

The smaller GIS footprint also opens up possibilities for future expansion. For petrochemical refineries in particular, space is often an issue. If an expansion of a GIS is needed, it can be done later using minimal site space, which may not be possible with AIS if the site does not offer enough space to accommodate the larger footprint of AIS. With some advance planning, GIS can create the possibility of future expansion at negligible cost, if desired. For example, constructing a building that is larger than necessary up front may seem wasteful at first. However, a building plan that allows for future extension by design means additions or expansions can be built at negligible cost in the future and at only incremental added cost in the present. The most important issue is ensuring the building structure allows the main bus of the GIS to be extended.

For example, one utility company in the Northeast US needed to upgrade its infrastructure by adding a 115kV GIS substation on a small urban site. The utility was also planning to eventually expand the substation, so the design included space and civil and electrical design elements in the building to accommodate future additions [15] In this way, GIS projects can enable operators to accommodate future expansions in a smaller footprint, sometimes significantly, without extending beyond a normal site footprint. This flexibility can add longevity to the substation as it needs to grow in future decades.

IV. SAFETY AND ENVIRONMENTAL CONSIDERATIONS

A. Arc-Resistant Design

One advantage of a GIS substation over AIS is its intrinsic arc resistance as the enclosure bolting is rated to withstand an arc. Further, operators face no exposure to the high voltage bus structure, which is entirely enclosed and typically includes a plenum and blowout panel designed to divert hot gases away from personnel. A passive arc-resistant protection system can be provided for AIS designs, but they can be complex and require a large footprint. Instead, arc-resistant GIS designs that have been tested to International Electrotechnical Commission (IEC) specifications are standard.

B. Fire-Resistant Design

Since GIS is in an enclosed housing, any faults remain within the enclosure. Additionally, no flammable material is used. The insulating gases are nonflammable, and construction materials are typically aluminum (rather than steel), which does not burn: "In fire tests on aluminium [sic] materials, when the temperature exceeds the melting point, in the range 600-660°C (1,112-1,220°F), the aluminium [sic] surface exposed to the fire can be seen to melt, but it does not burn" [16]. Similarly, control cables are halogen-free and flame retardant according to the IEC 60332-1 standard [17].

In general, a maximum service temperature around 105°C (221°F) is recommended, as exposure to higher temperatures can damage barrier and support insulators, but even that specification is solely performance related.

C. Intrusion- and Attack-Resistant Design

GIS also minimizes foreign intrusion (e.g., rodents) and environmental contaminants, as well as attempted intrusion with malicious intent. Rising threats against power infrastructure necessitate consideration of the security aspects of substation design. According to a *USA Today* analysis of federal energy records, the U.S. power grid is hit by a cyber or physical attack approximately once every four days [18]. Oregon, Washington state, and North Carolina have each faced recent armed attacks against substations and other energy infrastructure. In North Carolina in 2022, tens of thousands of people lost power for days as the result of damage to substations by armed assailants [19].

These incidents highlight the added value of protective buildings sheltering critical equipment by eliminating outdoor exposure and restricting access. Further, GIS buildings can be designed to offer additional protection from attacks, such as bullet resistant enclosures. The buildings can also be camouflaged by designing them to blend into the surrounding area. Reduced vulnerability to attack can potentially reduce the cost of security measures as well.

D. Environmental Sustainability Goals

SF_6, also known as sulfur hexafluoride gas, consists of one sulfur atom bonded to six fluorine atoms. This is the most common insulating gas used in GIS projects because it offers high dielectric strength (approximately 2.5x air), high arc quenching (approximately 100x air), and high heat transfer capacity (approximately 2x air). SF_6 is also nontoxic, nonflammable, noncorrosive, and chemically inert. The gas neither expires nor exhausts.

At the same time, SF_6 is also a powerful greenhouse gas, listed in the 1997 Kyoto Protocol as one of six greenhouse gases whose emissions need to be reduced [20]. Specifically, the global warming potential (GWP) of SF_6 is over 22 000 times that of carbon dioxide (CO_2), with atmospheric residence of up to 3,200 years [21]. As a result, some regulatory authorities have even considered banning, taxing, or otherwise forcibly reducing its use [22].

Even so, increased regulatory controls will not render SF_6 obsolete. For example, draft amendments to the regulation for reducing SF_6 emissions from gas-insulated switchgear from the California Air Resources Board proposes phasing out SF_6 usage for voltages under 145kV by 1/1/2025, for voltages between 145kV and 245kV by 1/1/2029, and for voltages over 245kV by 1/1/2031 [23]. However, these draft amendments allow for technical infeasibility exemptions if:

- Feasible non-SF_6 alternatives are not available by the phase-out date, or
- Available non-SF_6 alternatives do not fit the location or technical requirements of the project.

Notably, regardless of whether a new build is AIS or GIS, any usage of SF_6 gas in the breakers (which is still present in smaller quantities even in AIS breakers) will still have to follow regulations coming in the future. In other words, regulations such as these do not affect just GIS builds.

In the meantime, manufacturers are actively working to develop alternatives. In fact, new GIS technology eliminates the necessity of SF_6 gas, helping facilities meet environmental sustainability goals with newer, environmentally friendly insulating gas mixtures in place of SF_6. These non-SF_6 formulations eliminate one of the most serious concerns about GIS by offering insulating properties as effective as SF_6 with up to a 99% reduction in GWP. As a result, non-SF_6 alternatives make GIS a much more attractive option for organizations looking to reduce their carbon footprint and overall environmental impact.

These new formulations offer similar insulation, arc quenching, and footprint characteristics as SF_6 solutions, although particular specifications do vary according to manufacturer and most formulations are proprietary (see Table VIII). At present, limited voltage ranges are available, again varying according to manufacturer. Manufacturers are working to develop SF_6-alternative offerings for all voltage ranges currently available for SF_6 GIS equipment: “As the majority of SF_6 is still used in the electrical industry, the search for alternatives to SF_6 in this field is well advanced. Changing over in all voltage levels to Alternative Gases or technologies is considered inevitable.” [24]

TABLE VIII
NON-EXHAUSTIVE SAMPLE OF ALTERNATIVE GASES [24]

	SF_6	C_4F_7N	$C_5F_{10}O$	O_2/N_2
Boiling Point	-63.8°C	-4.7°C	+26.9°C	-183°C; -196°C
Atmospheric Dwell Time	3200 y	30 y	0.04 y	-
GWP	22 800	2,100 (<760 in some gas mixes)	< 1	0

V. CONCLUSIONS

The GIS substation market is poised to grow over the next decade, with an expected 34.8% growth rate in market size through 2028 [25]. That’s likely thanks to a number of demonstrable benefits GIS substations can offer when compared to their more conventional alternative, the air-insulated substation.

By shrinking the space needed to insulate equipment, GIS substations can be located on a variety of sites and are ideal when future modifications or expansions are expected. Experiencing fewer outages and fewer outage hours on average than AIS, GIS facilities offer greater uptime and less disruption. Taken together, these features of GIS builds can reduce maintenance requirements and extend lifespan significantly. Finally, by placing its live components within a sealed enclosure protected against environmental conditions, GIS equipment offer impressive O&M cost savings across the entire lifecycle of the equipment – potentially about half the total lifecycle costs of AIS builds.

These strengths are particularly noteworthy for petrochemical facilities that must often contend with site limitations, exposure to corrosive conditions, elevated operating costs, and aging electrical infrastructure, all of which are challenges that GIS is well-suited to resolve. Even better, innovation in the gas formulations used within GIS structures that eliminate the use of SF6 answers one of the chief objections to GIS builds and can help project owners meet environmental sustainability goals. Now, GIS projects can proceed with little to no environmental impact compared to SF_6-based builds. Compact, reliable, and cost-effective, GIS offers demonstrated advantages for building effective substations in less space and at lower cost.

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VII. VITAE

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