Gas Insulated Substation Definitions and Basics

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DEFINITIONS

This course is based on terms used in IEEE and IEC regulations. Several crucial terms are for better understanding of the presented material.

GIS - There are two terms presented in IEC “Gas Insulated Switchgear” and IEEE “Gas Insulated Substations.”

In IEEE C37.122 - Gas insulated switchgear (GIS): a compact, multicomponent device, enclosed in a grounded metallic case in which the basic insulating medium is SF6 gas and which typically includes buses, switches, circuit breakers, and other related devices.

In IEC 62271-203 - Metal-enclosed switchgear and control gear: switchgear and control gear devices with an external metal case were planned to be grounded, and complete except for external connections. There is no precise definition of GIS.

Metal-Enclosed Switchgear and Control gear - Switchgear and control gear devices with an external metal case were planned to be grounded and complete except for external connections, as described in IEC 62271-203.

Gas Insulated Metal-Enclosed Switchgear - Metal- enwrapped switchgear in which the insulation is received, at least partially, by an insulating gas other than air at atmospheric pressure, as described in IEC 62271-203. This definition typically relates to high voltage switchgear and control gear. Three-phase enwrapped gas isolated switchgear applies to switchgear with the three phases enwrapped in a common case. Single-phase enwrapped gas insulated switchgear relates to switchgear with each phase closed in a single independent case.

Gas Insulated Switchgear Enclosure - Part of the gas-isolated metal- enwrapped switchgear holding the isolating gas under the dictated conditions essential to keep the greatest isolation level safely, guarding the device against external impacts and giving a high degree of protection to staff, as described in IEC 62271-203. In IEEE C37-122, earthed element of the gas isolated metal-enclosed switchgear device holding the isolating gas under the dictated conditions essential to keep the needed isolation level, guarding the device against external impacts and giving a high degree of protection from an approach to live energized parts.

GIS Compartment - A part of a gas isolated switchgear assembly that is closed except for gaps needed for interconnection gives isolating gas separation from other compartments. A space may be assigned by the main elements in it, for example, circuit breaker space, disconnect switch space, bus space, and so on, as described in IEEE C37.122. A space of GIS as described in IEC 62271-203 as part of a gas isolated metal-cased switchgear, is completely closed except for gaps needed for interconnection and control. A space may be assigned by the main element held therein, for example, circuit breaker space or bus bar space.

Design Pressure of Enclosures - The greatest gas pressure to which a gas isolated switchgear case will be subjected under normal service operation, including the heating impacts of rated continuous current, as described in IEEE C37.122.

Gas Monitoring Systems - Any devices for measuring, signalizing, or providing remote warning of the condition or change in condition of the gas in the case, such as pressure, density, moisture level, and so on, as described in IEEE C37.122.

Gas Leakage Rate (Absolute) - The quantity of gas getting away by a time unit showed in units of Pa m3/s, as described in IEEE C37.122.

Gas Leakage Rate (Relative) - The absolute leakage rate associated to the total quantity (mass or volume) of gas in each space at the rated filling pressure (or density). It is defined in percentage per year, as described in IEEE C37.122.

Gas Pass Through Insulator - An internal insulator backing one or more conductors specifically made to provide the passage of gas between adjoining spaces, as described in IEEE C37.122.

Gas Zone - A part of the GIS that may be comprised of one or several gas spaces that have a common gas monitoring system. The case can be single-phase or three-phase, as described in IEEE C37.122.

Local Control Cubicle (or Cabinet) (LCC) - A cubicle or cabinet usually holding secondary devices including control and interlocking, measuring, indicating, alarm, annunciation, and mimic one-line diagrams related with the primary devices. It may also let in protective relays if defined by the user.

Support Insulator - An internal isolator backing one or more conductors, as described in IEC 62271-203.

Partition - Part of an assembly distinguishing one space from other spaces. It gives gas isolation and backing for the conductor (gas barrier isolator), as described in C37.122. A space as described in IEC 62271-203, which is a backing isolator of gas isolated metal enclosed switchgear distinguishing one space from other spaces.

Design Pressure of Cases - Relative pressure utilized to find out the design of the case. It is at least same to the maximum pressure in the case at the greatest temperature that the gas used for insulation can reach under defined maximum service circumstances. The transient pressure happening during and after a breaking procedure (e.g., a circuit breaker) is not to be studied in the decision of the design pressure, as described in IEC 62271-203.

Relative Pressure across the Partition - Relative pressure across the partition is at least same to the greatest relative pressure across the space during maintenance actions. The transient pressure happening during and after a breaking procedure (e.g., a circuit breaker) is not to be studied in the decision of the design pressure, as described in IEC 62271-203.

Operating Pressure of Pressure Relief Element - Relative pressure selected for the opening procedure of pressure relief elements, as described in IEC 62271-203.

Routine Test Pressure of Cases and Partitions - Relative pressure to which all cases and partitions are submitted after production, as described in IEC 62271-203.

Type Test Pressure of Cases and Partitions - Relative pressure to which all cases and partitions are submitted for type test, as described in IEC 62271-203.

Rated Filling Pressure pre - Isolation and/or switching pressure (in Pa), to which the equipment is filled before putting into operation. It is cited to at the standard atmospheric air considerations of +20 °C and 101.3 kPa (or density) and may be showed in relative or absolute conditions, as described in C37.122.

Bushing - An element that enables one or few conductors to go through a space, such as a wall or a tank, and isolate the conductors from it, as described in IEC 62271-203.

Main Circuit - All the conductive elements of gas isolated metal-enwrapped switchgear included in a circuit that is planned to transfer electrical energy, as described in IEC 62271-203.

Auxiliary Circuit - All the conductive elements of gas isolated metal-cased switchgear included in a circuit (other than the major circuit) planned to control, measure, signal, and modulate. The auxiliary circuits of gas isolated metal-cased switchgear include the control and auxiliary circuits of the switching elements, as described in IEC 62271-203.

Design Temperature of Cases – The greatest temperature that the cases can reach under defined maximum service circumstances, as described in IEC 62271-203.

Service Period - The time until a servicing, including opening of the gas spaces, is needed, as described in IEC 62271-203.

Transport Unit - Element of gas isolated metal-cased switchgear intended for shipping without being taken apart, as described in IEC 62271-203.

MIXED SWITCHGEAR TECHNOLOGIES

Mixed switchgear technologies relates to the following combinations:

- AIS in compact and/or mixed arrangement

- GIS in mixed arrangement

- Hybrid IS in compact and/or mixed arrangement

RATINGS

The objective of ratings is to precisely use GIS devices based on an electric system arrangement and features while decreasing the number of technical issues. These ratings give interchangeable answers that are discerned across the industry and decrease cost. The primary ratings are voltage, frequency, short time and peak withstand current, isolation level, current, duration of short circuit and auxiliary voltages and frequencies. In high voltage switchgear assembly, the ratings are described for elements such as circuit breakers and disconnect switches, and connecting conductors/bus, grounding (earthing) switches. Typically, they are addressed in IEEE C37.100.1 or in IEC 62271-1 standards for switchgear devices. For elements of high voltage switchgear like GIS, the ratings in the standards are followed to make criteria and applications in the field. The arrangement of GIS has to consider that the design and production costs of the metallic cases as pressure vessels of the GIS apparatus are huge. Due to this, some GIS arrangements are grouped to address several voltage ratings. One equipment technical standard addressing rated voltages of 110 kV, 123 kV, 138 kV, and 145 kV, is described by the same class of GIS with the same case.

Within this variety of voltage assortment, only several gas densities of SF6 gas distinguish between the different voltage levels. In terms of current ratings, the deviation between 2000 A, 2500 A, and 3000 A might only be a different number of contact fingers or different wall thicknesses of conductors.

RATED MAXIMUM VOLTAGE

The high voltage (HV) points in regulations start at ratings above 52 kV in both IEC and IEEE regulations. Below this voltage, the devices are treated as medium voltage (MV). The common GIS high voltage ratings can be classified into four design parts or device types for any producers, even if the split may differ somewhat. The lower high voltage ratings are in 52 kV to 72.5 kV range. The second level range includes 100 kV, 123 kV, 145 kV and in some cases 170 kV rating. The next level range covers 245 kV and 300 kV with one GIS type. The fourth level range lets in the 362 kV and 420 kV voltages with the same GIS type. The 345 kV voltage level is treated as 362 kV and is no longer advocated by standards. The third and fourth ranges are used mainly in in North America and Europe, usually 245 kV and 420 kV in Europe and 300 kV and 362 kV in North America. The reason behind this is the accessibility of technical solutions like isolators at the moment when the voltage levels were introduced. A summary of the voltage levels is shown in Table 1.

Table 1. IEEE and IEC rated voltage levels

		Rated max voltage Um	Rated power frequency withstand voltage	Rated switching impulse withstand voltage	Rated lightning impulse withstand voltage (BIL)
IEC	IEEE	kV RMS	kV RMS	kV peak	kV peak
X	X	72.5	140	-	325
X	X	100	185	-	450
X	X	123	230	-	550
X	X	145	275	-	650
X	X	170	325	-	730
	X	245	425	-	900
X	X	245	460	-	1050
X	X	300	460	850	1050
	X	362	500	850	1050
X	X	362	520	950	1175
X	X	420	650	1050	1425
X	X	550	710	1175	1550
X	X	550	740	1175	1550
X	X	800	960	1425	2100

There are only two rated voltage levels left in the IEEE and IEC regulations, which have two different possibilities for power frequency switching and lightning impulse figures, which are 245 kV and 362 kV. The 550 kV rated voltage gives two isolation levels for the rated power frequency withstand voltage.

RATED ISOLATION LEVEL

The ratings for isolation levels are gained from the power network to which the GIS element is linked. Network circumstances, like lightning hits into overhead transmission lines, their local probability, and their anticipated impact, are indicators for the over-voltages that may happen. In the cable network arrangements, the cable lengths and their associated over-voltages during switching procedures will impact this rating. Rated isolation levels are fundamental parameters for the GIS design and have a direct influence on the case diameter and, with this, a high cost influence in design and manufacturing costs. Each voltage level in IEC and IEEE regulations has the possibility of two or even more isolation levels. In GIS, the selection is typically made in favour of the greatest requirement for the GIS.

As presented in Table 1, in majority of the cases the shown rated power frequency withstand voltage, the rated switching impulse withstand voltage, and the rated lightning impulse withstand voltage for the related rated maximum voltage level is the greatest figure from IEC and IEEE regulations. Only the rated maximum voltage categorizations of 245 kV and 362 kV have the possibility of two voltage levels.

RATED POWER FREQUENCY

Typically used power frequencies for GIS are 50 Hz developed in Europe and 60 Hz developed in North America. Besides 16 1/3 Hz and 25 Hz for railroad technology use, most of GIS usages are with 50 Hz and 60 Hz. These two frequencies are disseminated world-wide and make regions and countries with one of the frequencies. Few countries like Saudi Arabia and Japan use both frequencies.

The dielectric impact to the GIS arrangement of these frequencies is insignificantly low. The thermal influence has to be conceived when the current rating is reaching the limits, since at 60 Hz the power density is greater and, with this, the thermal rise. Temperature boundaries should not be violated because of potential damage to insulators or contact elements.

RATED CONTINUOUS CURRENT

The continuous current rating is a fundamental design measure of GIS for contactors and contact sizing. The complex GIS arrangement allows close impact of the various elements such as circuit breakers, disconnect and ground switches, current and voltage transformers, and bus bars in terms of heat dissipation and temperature increase. Due to this, the IEEE and IEC regulations ask for temperature rise tests to support the adequate function of all elements that are part of GIS. A so-called standard bay arrangement will be utilized for this test. One of the factors defined to a GIS installation may indicate that the rated continuous current may be dissimilar for the busbar or the feeders depending on the substations' arrangement. Common rated continuous currents are presented in Table 2.

Table 2. GIS common current ratings related to voltage classes

Current (A)/Voltage (kV)	52-72.5	100-170	245-300	362-550	800	1100
5000-8000				X	X	X
4000-5000				X	X	X
3150-4000			X	X	X	
2500-3150		X	X	X		
1250-2500	X	X				

SHORT TIME RATED WITHSTAND CURRENT

The rated short time withstand current (I_K), the peak withstand current (I_p), and the short circuit duration (t_K) (presented in the Tables 3 and 4) are fundamental sizing arguments for GIS system. These figures have a high influence on the electromechanical forces to the isolators and conductors, and on the thermal rise, typically of the contact system. These figures are also evaluated by specific type measurements to affirm the satisfactory function of the several GIS elements, such as the bus bars, circuit breaker, disconnect and ground switch.

Table 3. Common GIS short-current ratings of related to voltage classes

Current (kA)/Voltage (kV)	52-72.5	100-170	245-300	362-550	800	1100
63-100				X	X	X
50-63			X	X	X	X
31.5-50		X	X	X		
25-31.5		X	X			
16-25	X					

RATED PEAK WITHSTAND CURRENT

The rated peak withstand current (I_p) is described by the DC time constant of the electrical network. The rated peak withstand current is described as a factor of the rated short time withstand current. Common figures in the network are 45ms for the majority of the voltage classes, and up to 120ms in ultra-high voltage (UHV) electrical networks. The associated factors are presented in Table 4. GIS devices are made to accomplish these demands.

Table 4. Common factors to compute rated peak withstand currents (I_P)

Network	Factor to calcualte I_P	DC constant (ms)
50 Hz up to 500 kV	2.5	45
60 Hz up to 500 kV	2.6	45
50/60 Hz 800 kV and above	2.7	60, 75,120

DURATION OF SHORT CIRCUIT

The rated duration of a short circuit (t_K) depends on the electrical network protection and is symmetrical. Over the years of network growth and upgrades, and with growing short circuit ratings, this figure has evolved to shorter times. A common figure today is 1s, but also 0.5s is applicable. In some applications, 2s or 3s may be needed. The duration of a short circuit has a major influence on the GIS design, and it is advised to keep this short (refer to Table 5).

Table 5. Rated short circuit duration (t_K)

	Rated short circuit duration, t_K (s)
Short	0.5
Standard	1
Long	2
Very long	3

RATED SUPPLY VOLTAGES

There are several different supply voltages that are used and they are addressed by the regulations. This high variation is expensive for substation design and should be cut down. Hence, the regulations provide some favoured figures. For existing substations, this may not be feasible but new substation arrangement should follow these advices (refer to Table 6).

Table 6. Rated supply voltages

	Rated supply voltages
DC	48 V, 110 V and 125 V
AC	208/120 V three-phase, 400/230 V three phase and 230/115 V single phase

GAS INSULATED SWITCHGEAR PROCESSES - SULFUR HEXAFLUORIDE

It is vital for an engineer to understand the basics physics of the system and devices being dealt with. Sulfur hexafluoride (SF_6) is used as isolating medium in GIS equipment. The first ionization potential of SF_6 gas is similar to nitrogen (N_2) while the size of the SF_6 molecule is much greater than a nitrogen molecule. This practically means that the free path for an electron collision in SF_6 gas is around a third of the path that it is in N_2. Kinetic energy is a function of velocity squared, and anticipating linear acceleration, the mean electron to molecule collision in SF_6 would have 16% of the mean energy of a collision in N_2.

As gas density is raised, the average free path is reduced and the electric field strength needed to speed up electrons to the required velocity to induce ionization also rises. SF_6 gas has also another feature that makes it higher-ranking insulating gas. It is electronegative. This practically means that SF_6 molecules will pull in electrons to make negative ions. This inhibits the extension of a discharge.

GIS CIRCUIT BREAKERS

The GIS equipment contains switchgear, switches and circuit breakers, linked with bus bars and bushings. The circuit breaker is the main element of any GIS. Breaking process in GIS circuit breakers is frequent topic in technical literature. It is sufficient to mention that the features that make SF_6 a highly effective isolating gas, along with the relationship between its thermal and electrical conductivity features as it modifies from plasma to an isolating gas, lead to SF_6 being great breaking medium.

As the majority of interrupter arrangements are common to live tank, dead tank, and GIS circuit breakers, it is allowed to talk about the circuit breaker as used in a GIS. The interrupter in a dead tank and the GIS use see very similar circumstances. The volume of the enclosing, being nearly the same, does not impact pressures and gas flows that impact the interrupter's operation. This is not the situation for a live tank circuit breaker as the smaller gas quantity does impact interrupter operation. This practically entails that an interrupter tested in a live tank breaker has to be retested in a dead tank/GIS enclosure to check its operation.

The transient recovery voltages (voltages that are noticed and measured across the circuit breaker contacts as it breaks) notice the same recovery voltages in either a dead tank/live tank or GIS use. Transient recovery voltage needs to be looked at in any usage.

GIS AVAILABILITY AND RELIABILITY

Availability and reliability are two crucial figures for the dispatcher of the electric power system for commercial, private, or business. The equipment in the electrical power system indicates high numbers in availability due to the high character of the products. The needs of reliable power transfer are integral element of the electricity cost, and the price of damages induced by power supply pauses are becoming more and more into the focus of penalty payments to pay off for financial losses. Apart from the quality of the elements, the influence of ambient circumstances like humidity, temperature, dust, salty air, ice, and many others are the most determining arguments of reliability values. In the situation of gas isolated devices like GIS, the influence of ambient considerations does not affect the high voltage part immediately, which enhances the GIS reliability figures. For a 110 kV GIS equipment the mean time between failures is more than 10,000 years based on existing GIS equipment that is already in operation. Typically, the compact size of the GIS allows indoor applications. In this situation, the GIS non-high voltage elements are under constant ambient indoor conditions.

GIS DESIGN

SF_6 established as the favoured breaking medium for high voltage circuit breakers so it was natural to broaden the usage of SF_6 to produce compact disconnect switches, surge arresters, ground switches, interconnecting bus, voltage and current transformers, and various terminations for connections to air insulated cables and overhead lines, and direct power transformer links.

SF_6 GAS

The SF_6 gas pressures and properties utilized in circuit breakers have shown as adequate for GIS. The dead tank type of circuit breaker, where the interrupter is put in an earthed metal tank and links are established to air isolated overhead lines or a bus bar using SF_6-to air bushings, can simply be converted for application in GIS by utilizing interfaces comprising cast epoxy gas barrier/support isolators at the nozzles of the tank. Double pressure interrupters were used in GIS technology, but existing arrangements use single pressure puffer interrupters. High breaking ratings led to a greater SF_6 pressure in the circuit breaker interrupter than is required for the other functional elements. The higher SF_6 pressure in the circuit breaker ends in a low temperature limit of about 20°C – below this temperature the tank has to be heated to stop SF_6 condensation. For GIS equipment these actions are not required, as GIS is sufficiently small for indoor application. Only those GIS elements that go outside the enclosing have to be of a lower pressure design. Measurements and tests indicate that the purity of the SF_6 does not have to be greater than 98%, but the SF_6 gas has to be very dry to avert condensation of water vapour, since liquid greatly decreases the dielectric strength. The SF_6, and the entire GIS interior, has to be “clean” from impurities that greatly reduce the dielectric strength. The GIS designer can be sure that SF_6 technology that is commercially available is fairly priced, very pure, dry and clean. Completed electrical stress levels tests have shown that for reliable SF_6 operation about 5 kV/mm RMS for power frequency and about 15 kV/mm peak for lightning impulse is sufficient however theoretical boundaries are greater, but from a practical point of view it has not been worthy to go after greater stress arrangements.

A fairly large physical size is required to transfer the usual high voltage substation continuous currents that range from 1000 A to 8000 A. Full scale tests are needed to verify that the arrangement is sufficient for the type test defined by standards. Practice has confirmed that for the SF_6 gas the lightning impulse test is essential; if that is successfully completed, the others should not be an issue.

The SF_6 heat transfer capacity is vital design aspect. For theoretical and practical viewpoint, temperature boundaries are defined by regulations for conductor contacts at 105 °C total temperature. The cast epoxy support isolator materials usually utilized start to cast off mechanical strength at around 120°C. The GIS exterior is limited to a safe-to-touch temperature of 70°C. The consequence is a temperature divergence between the conductor and enclosing of about 35°C. SF_6 gas transfers the heat produced by current in the conductor by conduction and convection and is transparent to most radiation. Theory and empirically derived calculations can be utilized to compute the temperature grow, including the enclosure heating due to circulating currents and if needed solar radiation. The computations have to be supported by continuous current tests under real circumstances and thorough devices so that no hot spots are neglected. The SF_6 gas is stable at these temperatures and not prone to aging –the SF_6 gas will be sufficient for the life of the GIS equipment.

Another important characteristic of SF_6 that is vital for the designer is the pressure growth due to internal faults and degradation due to interruption arcs, switching sparks, and internal faults. The pressure growth from breaking and switching sparks can be neglected. The pressure growth from an internal fault is predictably slow and without shock waves. SF_6 gas will be degraded by the arc heat, spark, and/or fault. Most of the degraded SF_6 will fast recombine into SF_6, but some of the reactive molecules (S, F, etc.) will react with impureness in the SF_6 gas (such as water vapor, H_2O) to create degradation by-products such as HF, SOF, etc. The GIS arrangement considers the conduct of SF_6 gas and arcs into account by using absorbants to limit quantity of degradation by-products, pressure vessel regulations to give guidance to reach sufficient enclosure strength in relation to internal fault pressure growth and use of an epoxy resin formula for support insulators that will be stall even in the case substantial levels of HF are anticipated in the gas compartment. It is not needed to plan for substitute or refilling of the SF_6.

ENCLOSING

The typical enclosing material is an aluminium alloy selected for a needed mix of mechanical strength, good electrical conductivity, resistance to corrosion and fair cost. Cast, extruded, and wrought manufacturing processes are utilized depending on the planned usage. For instance, a composite switch enclosing may be cast aluminum and a bus enclosing may be extruded. Enclosure elements may be welded. The circuit breaker is the greatest and heaviest physical GIS element and is usually the key physical attachment and fixed point associated to environmental and GIS thermal expansion forces. Circuit breaker is made to have strong tanks, nozzles, and supporting elements.

GIS OPERATING PRINCIPLES

GIS is totally capsuled, that is impervious to and distinguished from the external ambiance. This is a huge benefit from environment viewpoint such as ocean based oil rigs, particle or mist pollution sources. Nevertheless, because the gas isolated switchgear is totally capsuled, a needed visible disconnecting means cannot be directly accomplished. The grounding and disconnect switches, needed in both air and gas insulated arrangements, will have view ports in gas isolated devices.

GIS has a reduced “footprint” than a corresponding air insulated substation, usually less than half the area. Even though a gas isolated substation will initially cost more than a similar air insulated substation, the economics may rationalize its installation where land is pricey, such as city centres. GIS may also be rationalized when a low profile substation is required to “hide” a substation.

OPERATION

As a gas isolated switchgear element is isolated for servicing, it will be required to affirm the places of the grounding and disconnect switches. Since these switches are totally cased within the aluminum enclosure, it is essential for producers to allow for view ports. The view ports allow, by visual verification, to check the position of the different disconnect and grounding switches. In some situations, this can be completed with using just a flashlight. In other situations, at strange access points, a camera with a light source supplied by the producer is handy.

Gas isolated devices are typically furnished with a local control cabinet (LCC). Generally, this cabinet lets in control switches for the operation of one circuit breaker and its related grounding and disconnect switches and breaker alarms. The protective relays related with the GIS devices may or may not put in the same place. Since SF_6 gas behaves as a vital insulator, it is required to keep adequate density within the GIS devices. Hence, there will be alarm and trip contacts from sensors for each gas separation to warn staff or isolate devices when the insulation integrity is insufficient.

One of the advantages of GIS devices over its air insulated equipment is the minimal servicing that is needed of the GIS. This is mainly due to the breakup of the conductors and isolators from the outside ambience. Modern GIS devices have very low SF_6 gas leakage rates. The operation counter may help in finding out if any servicing will be needed on the mechanisms, but this is generally many years between maintenance.

SAFETY

Staff safety holds a crucial priority status when servicing a GIS. The metallic enclosure of the high voltage spaces are grounded where direct contact is not possible, except at the external links. This safety element is underlying in the GIS arrangement. Moving elements such as operation rods or motor drives are typically protected with protective plates or showed by colouring for greater safety. In case of an internal fault, pressure relief elements open the enclosing to free the hot gas to the surrounding internal elements. These pressure relief elements are made to guide the gas stream away from staff to save them and ensure their safety. So even in the very rare situation of an internal arc, the safety level kept is high. This has also been verified in specific GIS type tests.

To set up GIS inside indoor or outdoor substation safety regulations are further described in IEC 61936-1. Installation regulations are presented to integrate factory assembled and type-tested GIS equipment. Demands of grounding, accessibility, fire protection, safety of walkways and other areas are described.

GIS equipment is made and tested according to IEEE C37.122 or IEC 62271-203 standards. All measurements have to be completed for the GIS to be certified. Before testing, GIS must be produced and gathered in a factory in clean rooms. The design has to pass all type and routine tests. GIS equipment is tested according to specified on-site tests after erection, as defined in the mentioned regulations.

Extra demands for the GIS are associated to external links, the erection procedure, and servicing requirements. External links are usually made with transmission overhead lines, cables, coils, transformers or capacitor banks. The installation and erection should be coordinated in such a way as to avert risk to staff or damage to other devices.

DESIGN AND ERECTION DEMANDS

The GIS equipment should be organized to allow proper overview for operators about the bay structure. Vital elements for the erection, operation, and servicing should be quickly accessible and without danger for the operator. If required, ladders and walkways have to be given. Arrangement and access for dealing with the devices, equipment such as a crane, ropes, and hocks should be provided.

Adequate designs to link the GIS to external connections are needed to safely operate on site. Adequate working space is required and all metallic structures have to be grounded.

OPERATION PLATFORMS AND LADDERS

The great size of high voltage GIS typically at the 420 kV and 550 kV voltage levels may require platforms and ladders put in for operation and servicing needs. For instance, platforms or ladders may be required to verify the position of disconnect or ground switch through the view port. Hence, platforms or ladders should be part of the GIS structure.

These ladders and platforms have to be designed in such a way that safety is guaranteed from an operational point. Platforms are typically fixed to the GIS while ladders may be fixed or removable.

Figure 1. Ladders and platforms in GIS

GIS MONITORING ELEMENTS

Monitoring elements in GIS equipment should be made and put in such a way that they can easily be identified either by color and/or numbering. Monitoring elements are utilized for gas density reading and are put on the gas space. The older design of utilizing gas pipes to link the gas compartment to a central gas density control cubicle is disused since the raised risk of gas leaks from these pipes and their fittings.

In modern GIS technologies, gas density readers generally give only a red or green indication. Green means all is “OK, no gas loss” and red means “not OK, gas loss”. Switchgear will be automatically turned off by clearing the section from high voltage.

It is crucial that there is visible and clear marking of each gas space for the servicing staff. This assures that the gas space can clearly be described between the two gastight isolators of the gas compartment. Typically allots are sowed by outside coloring.

Figure 2. Gas density monitoring indicator

Other monitoring elements include operation counter or UHF antennas for partial discharge measure. Typically, when the GIS is in normal operation, it is not supervised by partial discharge (PD) measure since it is not required. Nevertheless, at the commissioning time, primarily at the greater voltage levels of 420 kV, 550 kV, or above, an on-site temporary PD measuring is utilized. The PD measurement devices are then linked to the UHF antennas of the GIS where safe access is required. After the commissioning is completed, the PD measuring devices are disassembled.

THERMAL EXPANDING

When current is going through the GIS equipment the conductor temperature will rise thus the enclosure temperature will increase. This can quickly arrive at temperature differences of 40K to 50K and will end in a thermal expansion breakup of the enclosing and conductor metallic materials. Thermal expansion forces are strong. To keep the GIS from mechanical tensions induced by thermal expanding, bellows need to be given to mechanically decouple the GIS bays. In the situation of direct transformer links, bellows are also needed to mechanically decouple the GIS and the transformer.

The technical demands are presented in IEC 62271-211.

UNDERGROUND CABLE CONNECTION TO GIS EQUIPMENT

Direct link of an oil or solid isolated underground cable will require a special enclosing joint to bridge the cable isolation to the gas isolation of the GIS equipment. This is the reason isolator cones are used and they are isolated with SF_6 gas on the GIS equipment side and with oil or solid isolation fittings on the underground cable side. The internal isolator cones are pressure equipment made to defy the GIS equipment gas pressure, which is generally 0.6 MPa to 0.8 MPa. The copper conductor of the underground cable and the aluminum conductor in the GIS equipment are linked by an integrated conductor in the internal isolator cone. The outer enclosing is linked to the underground cable shield or in some situations high voltage cable shielding is not linked to the GIS equipment enclosure to avert induced currents in the cable shield, which may heat up the underground cable. Another reason for isolating the underground cable shield from the GIS equipment grounding is in the case of cathodic corrosion protection of the underground cable. In these situations an isolating ring is used at the GIS equipment.

If such isolation rings are utilized, in the situation of disconnector switching in the GIS equipment, the generated high voltage transient over-voltages may induce lightning flashovers across the insulation ring. This creates noises and light flashing and may end in a staff accident.

Figure 3. Direct cable connection to GIS at 110 kV and single-phase insulated

Generally, the lightings are not dangerous for the GIS equipment or the underground cable, but they are for staff around the GIS equipment. Hence, in such situations it is advised to use surge arresters across the insulation ring to get around the high voltage transients.

Due to the high frequency of the transient voltage of several hundred MHz, it is essential to locate the surge arresters around the insulating ring. A minimum of four arresters are advised.

GIS BUILDING REGULATIONS

Typically, GIS building demands and fire standards for buildings are adopted on national or regional levels. The following demands and suggestions should be followed for areas and areas around high voltage switchgear fabrications in line with IEEE C37.122 and IC 62271-203.

LOAD AND CEILING

Modern GIS arrangements are handed over in large units. Generally, for the voltage levels of up to 145 kV, two whole bays are shipped on-site. For voltages up to 420 kV, one whole bay may be transported as well as anything above that, with elements of a bay being added on site for assembly. In any situation, weights exceeding several hundred kilograms or few tons have to be shipped on site in the building.

Hence, the GIS building ceilings and structure have to be sufficiently strong to support the load. Moreover the floor material has to withstand the forces produced by fork lifters or air lift equipment transporting the GIS bays. The weights have to be provided by the GIS producer.

Figure 4. View of a typical floor inside a GIS building

AIR CONSIDERATIONS

The GIS structure for an indoor GIS installation has to be waterproof to give indoor conditions as prescribed by the regulations. Depending on the local atmospheric considerations it may be required to air-cool the GIS building. Typically, this happens when temperature or humidity is very high, or if high air pollution is around the site.

Water condensation, usually when the GIS building is air-cooled, should be prevented to avoid corrosion. Cold air dryers, typically utilized with air-conditioning, are suggested. If this cannot be found, care should be exercised to stop the consequences of water leaking or condensation impacting working safety. Handrails or slippery-save walkways are usually required.

ELECTRIC ARC FAULT OVERPRESSURE

In the situation of an internal arc within the GIS equipment, the pressure inside the enclosing could rise to a point where a disc snaps, ending in the burst disc falling into the building space. GIS building wall, ceilings, and floors should be sufficiently strong to properly withstand pressure growth. The pressure load depends on the enclosing gas quantity and the short circuit rating of the devices and can be computed by the GIS producer.

PIPELINES

If the case, water pipelines exist in the GIS building, they should be put in such a way that they do not impact the GIS in case of failure.

BUILDING WALLS

The external building wall should be strong enough to resist rain, sun, wind, snow, and ice to save the GIS equipment from environmental impact. The walk halls that connect the indoor to outdoor GIS equipment should not impact the mechanical wall stability. If metal elements are utilized for wall halls they have to be earthed. Panels or parts that can be reached from the outside have to be mounted in such a way that they cannot be displaced.

BUSILDING WINDOWS

GIS building external wall windows have to be made in such a way that any entry is hard. Hence, the GIS building windows have to be placed more than 1.8 m above the ground, in line with IEC 61936. The glass may be made up from unbreakable material or the window guarded with an iron curtain.

GROUNDING/EARTHING DEMANDS

The very fast high frequency transients require a high frequency, low impedance to ground/earth. This low impedance is achieved by having more links between the concrete reinforcement steel grid and the grounding arrangement of the GIS building at various locations in the GIS building floor. Common solutions for the GIS equipment are to use a steel bar in the floor. At the GIS building wall more connections for the GIS building to air bushing is required between the GIS enclosing and the building wall. To stop good conductivity in the GIS building wall steel panels are typically integrated with multiple links to ground/earthing of the GIS building. Secondary devices utilized with the GIS equipment have to be properly designed and verified about their resistance against transient over-voltages of the secondary circuits.

BURN THROUGH OF ENCLOSURE

GIS burn through safety includes gas detection, ventilation, and personal access. Care has been exercised by type measurements of internal arcs in line with IEEE C37.122 and IEC 62271-203 to save staff and other devices.

OPERATION BEHIND PRESSURIZED ISOLATORS

Safety work directions to operate behind pressurized isolators are specified in maintenance regulations between end user and producer.

SF_6 RELEASE TO BUILDINGS

The regulations about safety to release SF_6 into buildings are part of mutual agreement between end user and producer. These regulations need to consider local standards to avoid too low oxygen concentration in surrounding air and health issues of SF_6 by-products.

Figure 5. Ground/earth connection of GIS using bolts or a steel bar in the floor (a) Bolted GIS fixing with grounding connection (b) Steel bar is the floor including grounding connection

GIS GROUNDING AND BONDING

GIS equipment is inherently safe since all energized elements, with the exception of SF_6-to-air bushings terminals, are closed in earthed cases and are not subject to incidental contact. Moreover, to assure staff safety and save devices, GIS installations apply different earthing patters to achieve system and protective grounding.

GIS VS AIS GROUNDING

GIS equipment is established under the same system parameters as AIS equipment. Nevertheless, with respect to earthing, one major difference is that GIS equipment is typically established on much smaller sites than AIS equipment. Accordingly, GIS equipment does not have the same benefits as large AIS switchyards where the station ground grid assists to disperse fault currents. Hence, in order to secure low impedance paths to ground for fault currents, decrease magnetic field magnitudes, and reduce transient over-voltages, GIS arrangements use grounding arrangements with multiple points. Multipoint earthing arrangements consist of short earthing conductors that link the GIS equipment at various points along the enclosures. These numerous earthing conductors allow for parallel paths to the GIS main earthing bus or GIS earthing mesh.

GIS ENCLOSING CURRENTS

In most GIS arrangements, each element is electrically linked either via flange links or external shunts. This ends in an uninterrupted enclosure throughout the GIS system, granting enclosure currents to go during normal service and under fault situations. Enclosure currents are an end result of voltages generated in the metallic case by effects of currents passing through the enclosed conductors, and can be categorized as induced, return, circulating, or fault currents.

During normal service, the return current on a GIS case can rise up to 90% of the operating current. In the case three-phase fault happens, the return current can rise up to 90% of fault currents. Hence, GIS return current conductors, flanges and shunts, are made for a full return current and fault conditions without outperforming the conductor’s thermal and mechanical boundaries.

Enclosure currents in three-phase GIS usages are not susceptible to circulating enclosure currents since all phase conductors are placed inside one enclosure, and the phase conductor’s electromagnetic fields cancel each other out.

In single-phase GIS arrangement, each conductor is placed within its own earthed case. Consequently, enclosure currents during normal service are made up of circulating currents. GIS producers generally supply conductors to link each single-phase case at more locations. These earthing links are interconnected across each phase case at intervals along the GIS equipment, as well as the ends of the cases to promote circulating currents and decrease magnetic fields. The phase enclosing interconnections also hold heavy circulating currents from going through earthing conductors and into the substation earthing grid.

TYPICAL RULES FOR GIS EARTHING

As mentioned in IEEE Standard 80, touch voltages can be more severe than step voltages in AIS equipment. With even more devices within reach in GIS, and induced voltages present on GIS cases, management of touch voltages is even more important in GIS equipment. To assess maximum touch and step voltages taking place on GIS cases during a fault, it is essential to complete an assessment on the substation earthing arrangement. Available earthing software should be utilized to complete checks to assess maximum touch and step potentials and ground potential growth.

In typical GIS applications there are two earthing grids that make up the earthing arrangement:

(1) the station earthing network, which is alike common AIS installation; (2) the GIS earthing mesh, that is a narrowly separated earthing grid (commonly 3–5 meters) implanted into the concrete slab in which the GIS equipment is put. A border earthing conductor around the building or case links the two earthing grids. Short links between the GIS cases and earthing mesh at intervals of around 10 meters, or in line with the producer's requirements, make up the multipoint earthing arrangement. Best patterns for GIS earthing and bonding include the following:

1. All earthing conductors should be as short as possible.

2. The earthing mesh and links should be in a position of conduct the system's fault currents without violating the thermal and mechanical boundaries.

3. All exposed earthing conductors should be saved against mechanical destruction and placed so as not to present a "trip hazard" to operation staff.

4. Adequate earthing and bonding methods, such as more conductors or voltage limiters, are needed at all separations within the GIS equipment. This includes SF_6 gas-to-air links, SF_6 gas-to-cable links, SF_6 gas-to-oil links, and where GIB exits the building.

5. Make sure all metallic building spaces, GIS support structures, and GIS maintenance platforms are adequately earthed.

6. Reinforcement steel in the GIS building floor should be linked to the GIS earthing mesh to further match ground potentials.

7. All secondary cables should be shielded with both ends of each cable shield earthed to mitigate potential electromagnetic interference.

VERY FAST TRANSIENTS IN GIS EQUIPMENT

Very fast transients are produced as an outcome of switching processes inside the GIS equipment or a dielectric break that induces a voltage collapse within the GIS equipment. The voltage break down generates traveling waves that spread away from the disturbance. The traveling waves spread throughout the GIS equipment with different reflections and mix to generate VFTs or over-voltages with a very steep rise rate. VFTs can induce electromagnetic interference in the local environment and in secondary circuits. As VFTs reach discontinuities, they can induce transient enclosure voltages (i.e., TEVs). TEVs are not direct danger to staff, but may create electrostatic sparks if the GIS multipoint earthing arrangement is not adequately placed.

GIS EARTHING CONNECTION DETAILS

- Each circuit breaker should have two earthing connection points.
- Special care should be given to SF_6 gas-to-air bushings where high frequency effects are dominant. A minimum of two earthing conductors should be placed.

Figure 6. SF6 gas to air bushings

- It is crucial to assess the earthing method at the GIS cable end unit. More conductors may be needed if directly bonded and voltage limiters have to be taken into account if single point bonding is used.

- All steel structures have to be earthed. Typically, a steel structure can be earthed to the nearest earthing point or GIS flange.

- GIS building slabs should include an imbedded GIS earthing mesh and steel reinforcement should be concrete. Reinforced steel should be bonded to the earthing mesh every 3 meters in both directions.

Figure 7. SF6 gas to cable connections

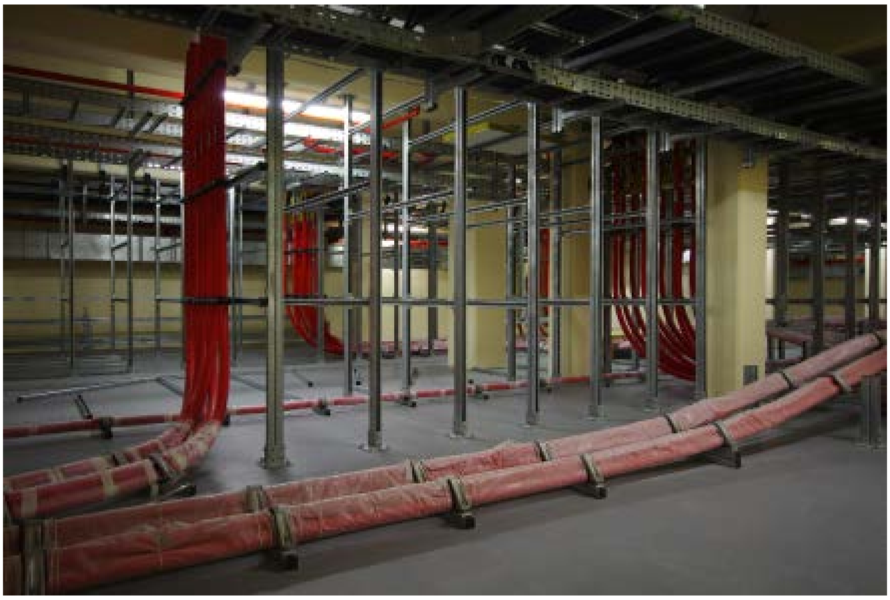

Figure 8. Steel structures

ELEMENTS FOR SELECTING GAS INSULATED SUBSTATIONS

The GIS substation development has been around world-wide for 60 years and GIS technology is becoming dominant asset for substation end users. Utility companies, government IPPs, military and industry are exposing many benefits of GIS. Nevertheless, when deciding if to select mainstream AIS, GIS, or a combined-technology solution there are many elements that have to be assessed. There is such an abundance of information, which can be understood from several respects, that it can make a user’s conclusion hard. As a matter of fact, the quantity of selection standards for AIS and GIS can block a user’s decision-making process. Hence, once a substation’s functional demands are determined, it is vital to find out, and even measure, which factors are crucial to the user’s particular usage.

Figure 9. Buildings

GIS SELECTION FACTORS

In order to assist in the decision-making procedure, it is crucial to precise and organize the benefits and disadvantages of AIS and GIS in a hierarchical fashion, and later on evaluate the elements according to the user’s requirements. GIS technology is most known for space-saving benefits, with substation footprints 15 to 25% that of the same AIS substation. Nevertheless, end users are gaining on extra benefits of GIS technology, such as enhancing vital infrastructure reliability, averting permitting obstacles, and decreasing planned outage durations.

For a user substituting older infrastructure, upgrading disused arrangements, expanding capacity or developing new capital, distinguishing the most pertinent elements empowers the end user to decide on the optimal substation design. All elements may not directly affect investment or life cycle prices, but may still be vital in the choice of the substation location and construction design. Following section presents typical terms and elements related to AIS and GIS substation evaluation:

- Aesthetics - Appearance factors and community adoption may have a dominant impact on substation’s area, height, and visibility. Typically, AIS is more difficult to disguise than GIS substation.

- Altitude - Elevation above sea-level, where devices that depend on air for its isolating and cooling medium, will have a greater temperature growth and a lower dielectric strength when serviced at greater altitudes. Both AIS and GIS technologies may require adjustment based on real substation altitude.

- Atmospheric contamination - Airborne pollution, such as dust, debris, salt and industrial pollution, can affect exposed electrical isolation. GIS equipment is usually installed indoors. Moreover, most GIS elements are hermetically closed inside an enclosure that makes GIS technology a superior solution in harsh atmospheric conditions.

- Availability - The amount of time that the service is available and the probability that power will be available.

- Audible noise - Sound levels generated by electrical devices may be an issue to the public. Both AIS and GIS technology noise has to be assessed for the user’s needs.

- Automation - Provisions for checking and supervising substation devices can be local or remote. GIS technology may have more possibilities for control since most circuit breakers are motor operated. Nevertheless, in GIS equipment these functions are gathered inside local control cabinet (LCC) and have to be incorporated with the user’s existing automation system.

- Capacity - A substation's load-carrying capacity, typically with reference to a power transformer's rating and determined by a system load assessment. The AIS and GIS switching devices have to be coordinated with the substation's capacity.

- Commissioning – Process that includes testing, inspection and documenting all primary and secondary elements needed before putting a substation into operation. Prefabricated and pretested GIS shipping elements can decrease inspection and testing time.

- Construction - Prefabricated GIS shipping elements usually decrease field installation prices and time. Nevertheless, prefabrication is typically less with greater voltages, and many GIS are put indoors, which asks for building construction.

- Community effect - Public concern of substation installations typically go around aesthetics, land use, safety, environmental effects and electromagnetic field (EMF) issues. GIS technology can be attracting when public approval is needed due to its small size and power to blend with the surrounding environment.

- Cost - GIS technology is costlier than AIS devices. Nevertheless, consideration of life cycle prices presents that GIS technology is less expensive and gives better service. Price comparisons should be founded on the overall life cycle prices, including devices, site development, land, normal servicing and maintenance prices, and forced outage prices based on reliability.

- Cutovers (planned disconnections) - During substation commissioning, one of the final steps is to transfer transmission lines and loads into the new substation. GIS technology has a benefit over AIS technology due to its smaller footprint and interface flexibility. Hence, many times GIS building can happen closer to connection points and therefore decrease cutover durations.

- Environment – GIS technology inherently decreases land and space use effects. Nevertheless, GIS equipment has more SF_6 sealed elements and thus gets more attention due to possible climate change effects. Despite this issue, possible total contributions of SF_6 to global atmosphere is miniscule relative to carbon emissions.

- Emissions (SF_6) - Extra treatment of SF_6 gas is needed due to greater amounts utilized in GIS. Since SF_6 is a greenhouse gas, it requires to be adequately handled.

- Expandability - AIS technology can be easily expanded. However, GIS technology is a perfect solution for expanding AIS when there is limited space, and planned outages are hard to get. Expanding existing GIS asks for the original design to allow provisions for future upgrades and may at times demand future infrastructure to be established early.

- EMF (electromagnetic field) - Magnetic fields due to conductor currents are decreased by GIS case currents and are usually less than those of AIS equipment. Even near GIS equipment, where greatest EMF levels can be experienced, exposure levels are typically well within allowable limits. Regarding public safety, evaluations have demonstrated EMF levels are usually orders of magnitude below safe levels.

- Failure rate - The average failure number of an element or unit of the system in a given time (typically a year). MTBFs are commonly less with GIS.

- Flexibility - The ease of servicing and time required to complete switching functions within a substation. This change with AIS and GIS arrangements.

- Interruption - A surcease of service to one or more clients, whether energy was being used or not. Interruptions can be assorted as instantaneous, temporary, momentary or sustained.

- Initial capital - All initial prices related to land acquirement, construction, licences, engineering design, civil construction, site work, purchase of devices, training, and installation of a substation. This differs between AIS and GIS arrangements, but AIS is usually less expensive.

- Land size. Property sizes are usually smaller when using GIS technology. Nevertheless, if land is cheap at the given site, this may not be crucial consideration.

- Location - Small GIS equipment footprints allow placing substations closer to end users, eliminating permitting needs, setting off high land prices, and hiding substation devices from the public.

- Life cycle cost - A price assessment that incorporates capital investment, land purchase, site preparation, reliability effects, servicing, and maintenance spending for the project life cycle with a defined interest rate. This method allows for an assessment of the pertinent considerations, weighted by the end user, to compute the overall life cycle price.

- Maintenance - Resources needed to upkeep substation devices. Frequency of GIS care is much lower than AIS because most elements are saved from the environment. Nevertheless, GIS maintenance processes ask for an extra training and GIS replacement elements may not be as easily available.

- Operation and maintenance (O&M) - This price takes into account all the fixed prices related to a substation, which are prices for property taxes, planned operation and maintenance, insurance and anticipated interruptions.

- Permitting issues - Indoor GIS technology may need enclosure or building licences, but complete permitting is typically sped up and/or decreased when compared to AIS technology. In addition, GIS technology can reduce effects on environmentally sensitive locations.

- Reliability - The part of time that an element or system is capable of completing the required process. The probability that it will be in operation where it can operate. The four crucial indicators for assessing reliability are SAIFI, CAIFI, SAIDI, and CTAIDI.

- Restoration - The return of electric power after an interruption, because of maintenance of the outage that caused the interruption, or because of reswitching of the power, or the initiating an alternate power generator.

- Safety - Safety is crucial to substation design and demands protecting the public, staff, by security, design, construction, training means and work practices. It is also crucial to note that safety starts during the engineering and equipment selection process.

- Security - A terror such as terrorism, vandalism or unauthorized persons getting into the substation. Usually, threats are minimized with GIS because the substation is placed indoors and energized elements are sealed.

- Seismic - The power of substation elements to resist forces produced by earthquakes. GIS usually has better seismic capability than similar AIS.

- Site preparation - Site development that includes all earth work such as cut, fill, grading, and drainage. GIS substations usually minimize the degree of earth work and civil work.

- Soil conditions - Features of the surface where a substation will be placed. These features will assist determine the foundation demands for the substation devices. Detailed assessment of resources needed to develop the particular site is suggested to decide if AIS or GIS technology is more useful.

- Stability - The power of an electrical system to return to a steady state after a collapse.

- Unique elements - Capacity coupled voltage transformers (CCVTs), load break switches and wave traps are typically not part of GIS installation. Such elements are needed to be air-insulated once the circuit leaves the GIS.

- Weather - Elements such as wind, ice, storms, rain, temperature, snow, and humidity may impact a substation's service. GIS technology tends to resist extreme environmental effects since it can be put indoors and GIS elements are hermetically closed inside cases.

- Staff training - Resources needed training the staff the correct processes of operating and handling substation devices. GIS asks for additional training.

Previously mentioned considerations for selecting AIS or GIS technology can be classified into three major groups: power system demands, such as reliability and availability; environment, such as place and climate; and financing, with respect to installation, operation and maintenance. Also, these considerations can be further classified as quantitative or qualitative since some are more easily quantified than others.

POWER SYSTEM CONSIDERATIONS

Considerations for selecting AIS or GIS technology start to come along in the asset planning stage. Once power system or transmission planning has decided the requirement for a retrofit or green-field substation, different elements have already been assessed, such as system stability, reliability, and load flow needs. The possibility to choose AIS or GIS technology at this point may be early, but data made during the planning process may already start guiding the user and investor to a suggested solution.

ENVIRONMENT CONSIDERATIONS

Locations with harsh conditions, such as poor soil, great air pollution, high seismic, or storm surge, are possible considerations created by the natural environment of a potential substation location. Nevertheless, other qualitative elements associated to the environment, such as aesthetics to the local district, licensing issues, and/or urban area effects can play into the optimal substation solution.

ECONOMIC CONSIDERATIONS

Economic assessment of an asset depends on the importance a substation user gives to each determining element. Also, dominating elements can change with each substation usage. Hence, in order to comprehend the complete investment of a substation project, many end users are turning to life cycle cost assessment. This assessment provides the user with data on how much a substation will cost over the lifetime of the devices. When AIS is cross compared to GIS technology with respect to the upfront investment price, most of the time AIS technology will result in the least expensive answer. Nevertheless, factoring in land purchase, licensing, site preparation, and O&M prices, gives a more holistic approach and may alter the optimal substation solution.

Innovation or non-traditional designs, such as GIS technology, can provide more reliability for the same budget under the right considerations. That is why it is vital for traditional engineering techniques, such as N-1 assessment, to be highlighted with a reliability-based life cycle cost planning approach.

CONCLUSION

When determining between AIS or GIS technology, some elements alone, for example aesthetics, may be an overcoming impact on a user's conclusion. Nevertheless, most of the time the best conclusion asks for assessing many elements and soliciting input data from many sections within an investor's organization. It is also critical to note that the optimal substation arrangement may not be solely AIS or GIS. Sometimes a mix of the two (i.e., hybrid or mixed-technology) might be the best arrangement. Typically, most of the factors will prefer GIS technology, but it is the value or importance given to the considerations that decides if the return on investment is justifiable to choose GIS over AIS technology. Consideration that can be measured should be assigned importance weights based on the user's needs.