21, rue d'Artois, F-75008 PARIS
http : //www.cigre.org

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Gas Insulated Substations (GIS) for Enhanced Resiliency

G.W. BECKER
POWER Engineers, Inc.
USA

SUMMARY

Resiliency is defined as "a means to withstand and to rapidly recover from disruption." The "Grid of the Future" must be resilient. Electrical substations must also be resilient and operate safely and reliably irrespective of the environments in which they reside. Grid strengthening efforts should improve substation reliability, inherently enhance emergency response and improve recovery strategies related to naturally or human-caused physical events that damage electric substations.

Natural events such as severe weather, are the primary cause of unplanned power outages in the United States. There are a range of natural events that can cause high impact consequential damage to an electric substation, and include storms, naturally occurring environmental conditions, earthquakes, floods, wildlife etc. The severity and impact of recent weather events such as superstorms, large scale tornado outbreaks, coastal flooding and inland river flooding and severe thunderstorms accompanied by strong straight-line winds have prompted substation owners to examine design strategies to limit potential damage to substations due to natural events.

Human-caused physical attacks and criminal activity directed at electric substations can be high impact events that cause consequential damage and have long lasting effects. As a result of recent criminal attacks on critical substations, many utilities are examining design strategies to mitigate the effects of criminal activity directed at substations in conjunction with limiting potential damage to substations due to natural events.

Historically, substation designs for the most part have been based on standardized engineering practices and traditional air insulated technology. Given the challenges associated with the threats posed by high impact naturally and human-caused physical events that can damage substations, many utilities are turning to gas insulated technologies as a more resilient solution to harden their substation infrastructure.

This paper discusses benefits considering the use of gas insulated switchgear in the design and construction of electrical substations to harden against infrastructure damage due to natural and human-caused physical threats to substations.

KEYWORDS

Resiliency, natural physical threat, human-caused physical threat, GIS

george.becker@powereng.com

INTRODUCTION

Electrical substations, especially transmission substations, generation interconnecting substations or substations serving critical loads function as part of critical infrastructure that is essential to the well-being and safety of the public. Ideally, these substations should therefore be designed to be immune to the effects of natural catastrophic threats and nefarious human-caused physical threats. It is impossible to design a substation that is 100% immune to naturally and human caused physical threats. However, well planned substation designs can be engineered and constructed, so that substations serving critical infrastructure are sufficiently hardened to provide the necessary reliability for increasing public demands, and more critically minimize the impact of damage and facilitate fast emergency response. It is possible to make the damage less severe, prolong service and restore service more quickly with a sufficiently hardened facility and a layered approach to physical security.

The aftermath of storms such as Superstorm Sandy and Hurricane Katrina, as well as the physical attack on the Pacific Gas and Electric Company's Metcalf Transmission Substation has increased pressure on utilities and municipalities to limit electric system outage frequencies and their durations. In addition, there is an overall heightened awareness among governmental agencies and utilities to harden critical infrastructure, thereby improving grid system reliability in preparation for major storm events and potential nefarious human-caused physical threats.

Conventional substation solutions, based on standardized air insulated designs, may not provide the best approach for critical substations located in areas susceptible to storms, naturally occurring environmental conditions, earthquakes, floods, wildlife or other natural threats, or physical attacks and criminal activities.

For example, Superstorm Sandy caused a potentially catastrophic storm surge and inundation of coastal flood waters that posed significant challenges to emergency responders and disaster relief efforts. Power outages caused by deficiencies in some traditional substation designs, and sometimes due to aging infrastructure, further compound these challenges and can delay emergency response. In addition, with growing populations in coastal areas, there is an increased risk of property damage and loss of life.

The National Oceanic & Atmospheric Administration (NOAA) identifies the following potential exposure to extreme weather:

- From 1990-2008, population density increased by 32% in Gulf coastal counties, 17% in Atlantic coastal counties, and 16% in Hawaii (U.S. Census Bureau 2010)
- Much of the United States' densely populated Atlantic and Gulf coastlines lie less than 10 feet above mean sea level
- Over half of the nation's economic productivity is located within coastal zones
- 72% of ports, 27% of major roads, and 9% of rail lines within the Gulf Coast region are at or below 4-foot elevation
- A storm surge of 23 feet can inundate 67% of interstates, 57% of arterials, almost 50% of rail miles, 29% of airports, and almost all ports in the Gulf Coast

For example, along the U.S. northeast coast line NOAA places the return period for a Category 3 storm between 68 and 70 years on the southern coastline of New England. Likewise, NOAA places the return period for Category 3 storms between 84 and 110 years along the Mid-Atlantic coastline, and between 85 and 170 years for the Northern New England/Maine coastline.

Another aspect to evaluate is the potential for recurring storms of specific severity to a specific area. For example, the NOAA has maintained records that show all hurricanes making landfall within 75 nautical miles of New Haven, CT since 1842. Within this period, nine hurricanes made landfall in New York and Connecticut:

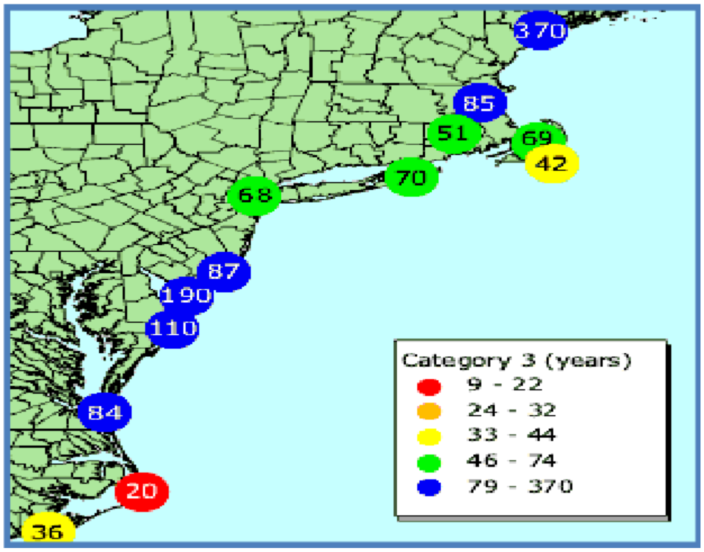


Figure 1 – Courtesy of National Hurricane Center (NOAA website)

Likewise, the Metcalf sniper attack was a "sophisticated" assault on Pacific Gas and Electric Company's Metcalf Transmission Substation located in Coyote, California, near the border of San Jose, on April 16, 2013, in which gunmen fired on 17 electrical transformers. The attack resulted in over $15 million worth of damage.

Seventeen transformers were seriously damaged. To avert a black-out of the critical “Silicon Valley Area”, energy grid officials were forced to reroute power from nearby power plants to the Silicon Valley Area. The damage at the Metcalf Substation and the action of reconfiguring the transmission system to continue to serve critical loads put the grid in a first contingency outage scenario for an extended period.

Figure 2 – Courtesy of Google Maps (Google Maps website)

This paper will focus on "actions" which are part of the methodology of prepare, prevent using GIS, respond and recover with respect to the use of gas insulated technologies to harden substations against natural catastrophic threats and nefarious human-caused physical threats.

The "prepare" actions consist of identification of threats, identification of the vulnerabilities with respect to the identified threat, assessment of the impact of the threats and maintaining an ongoing awareness of new risks and evolving threats.

The "prevent using GIS" actions consists of utilizing substation designs that are sufficiently hardened against natural catastrophic threats, utilizing substation designs that are based on a layered approach to physical security and integrating enhanced shielding measures. The effectiveness of these actions is greatly enhanced using gas insulated substation designs.

The "respond and recover" actions consist of damage assessment, securing the substation area and perimeter and initiating the process of repairing or replacing substation components that may have incurred damage and returning the substation to full operating condition.

PREPARE

The definition of resiliency in general is "a means to withstand and to rapidly recover from disruption." In the context of critical infrastructure, resiliency is "the ability of a facility or an asset to anticipate, resist, absorb, respond to, adapt to, and recover from a disturbance."

Preparation in anticipation of a threat(s) or disturbance(s) is the first step to designing a truly resilient substation. Substation owners must "Know the Threats, Vulnerabilities and Impacts." The specific threats to a substation may be different based on the location of the substations and the climate it resides in. The assessment of threats and vulnerabilities of a substation site and vulnerabilities of specific assets is the initial step in fully characterizing the threats.

To effectively prepare for potential threats to a substation the following actions need to be accomplished:

- Identification of the major physical threats to the substation (naturally and human-caused) and their characteristics
- Identification of the vulnerabilities with respect to the identified threats
- Assessment of the impact of the threats
- Maintaining an ongoing awareness of new risks and evolving threats

The following are short descriptions of the major naturally and human-caused physical threats to electric substations and potential impacts. These threats do not encompass all possible threats, but they are the major threats that are recognized as being potentially damaging to substation infrastructure.

Naturally Caused Physical Threats

Tropical Cyclone Winds

Strong winds from a tropical cyclone can damage or destroy vehicles, buildings, bridges, personal property and other outside objects, turning loose debris into deadly flying projectiles. In the United States, major hurricanes comprise just 21% of all land falling tropical cyclones, but account for 83% of all damage. These are long duration events.

Tropical cyclones can cause serious damage to air insulated electric substation equipment because the winds can produce flying projectiles that damage insulators, switches and bushings as well as other critical equipment in electric substations.

Tropical Cyclone Heavy Rains

The thunderstorm activity in a tropical cyclone produces intense rainfall, potentially resulting in flooding, mudslides, and landslides. Electric substations that are particularly vulnerable to freshwater flooding may be at a high risk for damages associated with these threats.

The wet environment in the aftermath of a tropical cyclone, combined with the heavy salt contamination of the air insulated electric substation equipment can cause both short term and long term damage.

Storm Surge and Coastal Flooding

A storm surge, storm flood or storm tide is a coastal flood or tsunami-like phenomenon of rising water commonly associated with low pressure weather systems such as tropical cyclones and strong extratropical cyclones. The severity of the storm surge is affected by the shallowness and orientation of the water body relative to storm path, as well as the timing of tides.

Since much of the United States' densely populated Atlantic and Gulf coastlines lie less than 10 feet above mean sea level, storm surge is a very credible threat to electric substations in these areas. During a storm surge or coastal flooding event, access to a substation can be hindered and substation equipment can be submerged. Storm surge can produce large floating objects that can damage substation equipment.

Inland River and Flash Flooding

Inland river flooding can cause damage to electric substations very similar to the damage caused by storm surge or coastal flooding. Flash floods can also cause similar and usually more serve damage, except that flash floods occur in a much shorter time frame, and they involve large volumes of water travelling at great speeds and with tremendous force. Flash floods usually always carry large floating objects that can damage substation equipment.

Severe Cold, Heavy Snow and Ice

Most electrical equipment sold for outdoor use is designed and built to international standards that require the equipment to operate within design parameters with no loss of performance between -30°C (-22°F) and +40°C (+104°F). However, a significant number of utilities operate in territories that are subject to temperatures below -30°C (-22° F) or even 50°C (-58°F). Equipment subjected to such low temperatures can be affected in a number of ways, depending on its construction, insulating medium, lubricants used for its moving parts, gaskets and seals and materials used for fabrication,

High levels of snow and ice storms affect air-insulated substation equipment in different but equally damaging ways, often leading to equipment failures, alarms and occasional blackouts if multiple pieces of equipment are affected. Heavy snow not only affects access to equipment in the substation, but also the safety of personnel and the operation of the substation.

The build-up of ice on electrical conductors and steel frame power structures in air insulated substations can reach unsustainable weights. Built-up ice can accumulate on porcelain bushings and insulators, eventually causing line-to-ground flashovers, taking the equipment out of service.

Tornados

Tornadoes have a shorter and more targeted impact than other storms such as tropical cyclones, or ice storms. Tornadic activity may accompany tropical cyclones and severe thunderstorms. The devastating wind energy from tornadoes makes hardening air insulated designs expensive and improbable with respect to the prevention of outages. The intensity, frequency and change in expected location cause significant outages for utilities that they may not be prepared for with air insulated substation designs.

Severe Thunderstorm Micro Bursts

A microburst is an intense small-scale downdraft produced by a thunderstorm or rain shower. A microburst often has high winds that can knock over fully grown trees. They usually last for seconds to minutes. Microbursts can also damage substation equipment be putting extreme downforces and moments on cantilevered equipment and strain buses.

High Straight-Line Winds

High straight-line winds associated with a land-based, fast-moving group of severe thunderstorms also known as “derecho,” can cause hurricane-force winds. Unlike other thunderstorms, which typically can be heard in the distance when approaching, a derecho seems to strike suddenly. A derecho moves through quickly but can do much damage in a short time to air insulated substation equipment.

Earthquakes

Air insulated substations contain structures to support electrical equipment at significant heights above ground level. These structures are mounted on footings, the anchorage to the footings supporting the equipment is frequently inadequate to prevent overturning or slipping during earthquakes due to the large forces and moments on the structures. Therefore, earthquakes can cause major damage to air insulated substations.

Severe Humidity

Elevated humidity levels will provide environmental conditions that promote increased fungal and microbial growth. Fungal and microbial growth can have detrimental effects on electrical utility equipment. This increased prevalence of fungus and mold on air insulated substation electrical equipment can cause premature outages, power failures, increased maintenance, and equipment failure.

Desert and Severe Heat

Heat is a prime enemy of electrical equipment. Elevated heat levels, above nameplate temperatures, can cause premature failure of air insulated substation equipment increasing maintenance and operational costs to the utility. Heat and drought environments create large amounts of dust and drying out of the soil that the substation is built on. The dust can cause mechanical operation issues and the dry soil can affect ground conductivity of the substation ground grid. Ultra-violet (UV) deterioration of materials can also be an issue.

Human-Caused Physical Threats

Human-Caused Physical Attack

Air insulated substations are vulnerable to human-caused nefarious physical attack unless they are significantly fortified at their perimeter and protected from above. Fortification of large air insulated substations is extremely expensive. Air insulated substations like the Metcalf Substation can be targeted with projectile weapons, bombs, air assault vehicles (i.e. drones) and physical attack using hand tools and machine tools by intruders. They are particularly susceptible to physical attack because of the area they encompass, their line of sight exposure and their large perimeter.

Human-Caused Criminal Theft

Air insulated substations are also more susceptible to criminal theft for the same reasons they are vulnerable to physical attack, large area and large perimeter. Intruders can find multiple weaknesses in the perimeter protection of the substation to enter and steal equipment and materials and possibly cause outages.

"Know the Threats, Vulnerabilities and Impacts"

The key to designing a truly resilient substation is to methodically assess what could happen and the vulnerabilities within the substation that need to be addressed. While the NERC requirements are focused on addressing a physical attack, substations fail for other reasons as well. Most of the utilities approach the assessment and subsequent planning from a more holistic perspective that includes physical attack, natural disasters or simply age-related failures.

The following is an example characterization of a major natural physical threat to an electric substation, the tabulated vulnerably of equipment and the potential impacts of the threats to the substation and electrical system:

Identified Threat and Characteristics	Vulnerability of Personnel and Equipment	Perceived Impact of Threat
Tropical Cyclone Storm Surge and Coastal Flooding	Flooding – submerged electrical equipment, access/egress problems and dangers for personnel, large floating objects Salt contamination – insulators, bushings, connectors, control/power /termination cabinets Long term corrosion – steel, cables, termination points	Requirement to de-energize the substation to minimize potential for major equipment damage due to faults. Long term restoration of equipment Critical power flows and critical load interrupted, national security risks and public safety risks

The following is an example characterization of a major human-caused nefarious physical threat to an electric substation, the tabulated vulnerably of equipment and the potential impacts of the threats to the substation and electrical system:

Identified Threat and Characteristics	Vulnerability of Personnel and Equipment	Perceived Impact of Threat
Terrorist Physical Attack Sniper Attack with Heavy Small Arms Ammunition	Personnel at the substation can be targeted Puncture and rapid leakage of insulating fluids Destruction of support insulators for HV equipment Destruction of bushings on HV equipment	Threats to human life of workers Long term restoration of equipment Critical power flows and critical load interrupted, national security risks and public safety risks

PREVENT

Effective prevention of most catastrophic damage to substations can be achieved by using gas insulated switchgear as part of the design of substations that are critical to the electric grid and vulnerable to major threats.

Gas insulated switchgear provides the substation owner with the following advantages with respect to substation design and cost while enhancing resiliency:

- A smaller substation footprint (area and perimeter) that can be located inside a hardened building, underground structure or elevated structure
- Expansion of the security perimeter of the substation
- Reduced construction time and schedule risks during construction
- More easily located near load centers and critical infrastructure
- More easily disguised and aesthetically pleasing with the opportunity for no overhead line entry, “out of sight, out of mind.”
- Approximately 15 times the reliability of an air insulated substation performing the same duty

The Tropical Cyclone, Storm Surge and Coastal Flooding Example

Elevating an entire transmission substation is challenging due to the amount of space required for increased electrical clearances at higher voltages. The corresponding amount of earth work, additional concrete for raising foundations, and increased steel requirements to elevate substation structures may not be feasible. Even if AIS (air-insulated substation) equipment is raised out of projected storm surge or flood levels, the substation will remain “outdoors” and is still vulnerable to other elements of the tropical cyclone.

Based on prior installations and case studies, elevating transmission substations with “indoor” GIS (gas-insulated switchgear) has proven to be an excellent solution to flood-prone substations, especially in coastal areas. GIS provides many unique benefits, such as a significantly reduced-footprint which often allows construction in small vacant areas of existing switchyards. This construction technique can solve permitting issues and allow existing substations to remain operational during GIS construction, thus providing reduced outages and shorter cutover durations.

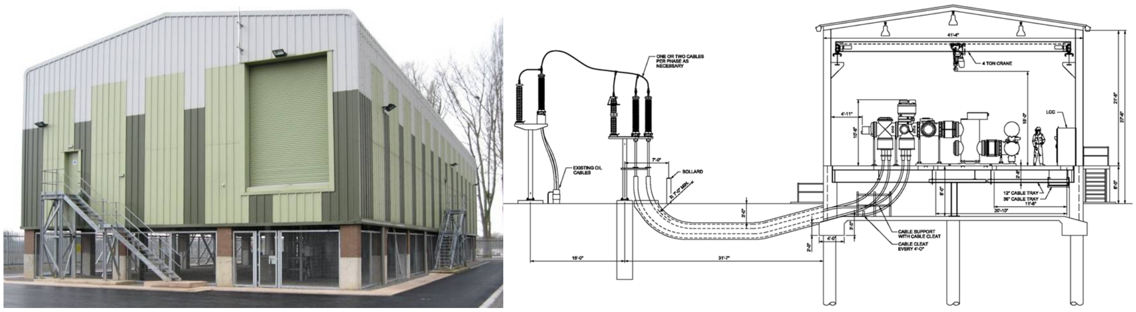


Figure 3 – Elevated GIS Substation Concept

By elevating a GIS substation above predicted storm surge and flood levels, risk of flooding equipment areas is virtually eliminated. In fact, according to the “Economic Benefits of Increasing Electric Grid Resilience to Weather Outages” paper issued by the White House; “Common hardening activities to protect against flood damage include elevating substations and relocating facilities to areas less prone to flooding. Unlike petroleum facilities, distributed utility T&D assets are not usually protected by berms or levees. Replacing a T&D facility is far less expensive than building and maintaining flood protection. Other common hardening activities include strengthening existing buildings that contain vulnerable equipment and moving equipment to upper floors where it will not be damaged in the event of a flood.”

In addition, by installing GIS inside an elevated substation, wind and atmospheric contaminates (e.g. dust, salt, industrial pollutants, etc.) cannot impact the substation’s operation. Since GIS equipment has all primary electrical components enclosed and in insulated with SF_6 gas, reliability improves significantly due to no external influences. Therefore, the power grid realizes benefits of improved reliability, as well as safety, and many times improved life cycle costs.

These concepts of using enclosed GIS in hardened buildings or structures are applicable to all major natural physical threats to substations. GIS significantly reduces the physical area and perimeter of the substation. This enables the substation owner to employ the following construction methods for substations to reduce the impact of Naturally Caused Physical Threats, catastrophic events and enhance resiliency:

Identified Threat/Impact	GIS Enabled Construction Method
Tropical Cyclone Winds	GIS can be installed in a low-profile enclosure/structure that is rated for tropical cyclone force winds. Incoming and exiting transmission and/or distribution lines can be routed underground to protect line terminations.
Tropical Cyclone Heavy Rains	GIS can be installed in a low-profile enclosure/structure that is rated for tropical cyclone force winds which consequently mitigates the salt contamination issues associated with tropical system rains.
Storm Surge and Coastal Flooding	GIS can be installed in a low-profile enclosure/structure that is rated for tropical cyclone force winds and is elevated above the maximum predicted storm surge level.
Inland River and Flash Flooding	GIS can be installed in many locations that a similar AIS cannot. This increases the options of constructing the substation away from the impacts of rivers and areas that are prone to flash floods. If relocation is not an option, then the GIS can be installed in a low-profile enclosure/structure that is elevated above the 500 year inland flood level and on piles that are not affected by surface flash floods.
Severe Cold, Heavy Snow and Ice	GIS can be installed in a low-profile enclosure/structure that is rated for snow and ice loads. The GIS enclosure /structure can be climate controlled to mitigate the effects of low temperatures on the SF_6 filled equipment and all electrical equipment.
Tornados	GIS can be installed in a low-profile enclosure/structure that is all or partially underground. Incoming and exiting transmission and/or distribution lines can be routed underground to minimize the impacts to line terminals.
Severe Thunderstorm Micro Bursts	GIS can be installed in a low-profile enclosure/structure that is all or partially underground. Incoming and exiting transmission and/or distribution lines can be routed underground to minimize the impacts to line terminals.
High Straight Line Winds	GIS can be installed in a low-profile enclosure/structure that is rated for tropical cyclone force winds and for straight line "derecho" wind forces as well.
Earthquakes	GIS is inherently resilient with respect to the forces of an earthquake. The GIS has a low center of gravity, minimized structure heights and extensions which reduce the effects of external forces and moments. GIS is a highly standardized modular building block design that is seismically qualified as a complete system capable of withstanding at least 0.2 times the equipment weight applied in one horizontal direction, combined with 0.16 times the weight applied in the vertical direction at the center of gravity of the equipment and supporting structure.
Severe Humidity	GIS can be installed in a low-profile enclosure/structure that is climate controlled to mitigate the effects of high dew points and minimizes fungal and microbial growth.

Identified Threat/Impact	GIS Enabled Construction Method
Desert and Severe Heat	GIS can be installed in a low-profile enclosure/structure that is climate controlled to mitigate the effects of high temperatures on equipment ratings, UV and minimize dust impacts on mechanical seals. Also, since the GIS grounding grid system is less reliant on soil moisture within the substation, ground conductivity issues can be minimized.

GIS provides enhanced resiliency for each of the identified threats/impacts individually. But when the benefits of the GIS Enabled Construction Methods are combined, the result is a truly resilient substation that is largely immune to most, if not all, naturally caused physical threats.

The Terrorist Physical Attack Example

The successful protection of substation equipment from human-caused nefarious physical attack requires a layered security approach. The following figure shows the widely accepted asset protection basic philosophy which is best approached through three steps:

- The application of concentric rings of security measures
- Inner most layers of security protect the most critical assets
- A structured process for evaluating protection based on impact and risk

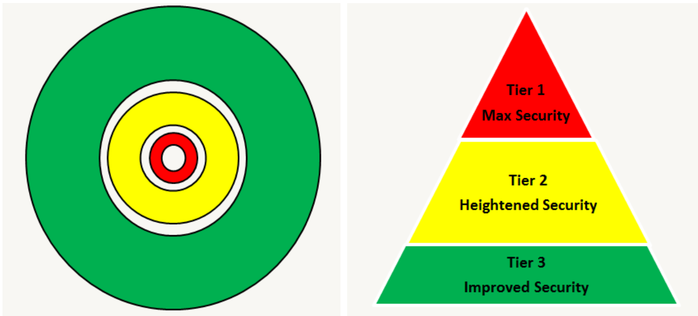
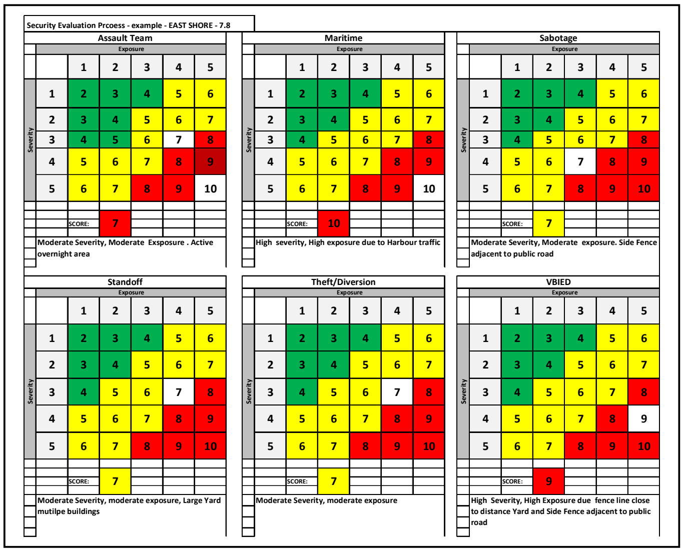


Figure 4 – Asset Protection Basics

The successful protection of substation equipment also requires some form of threat characterization and classification of substations. Threat characterization is accomplished by conducting a threat assessment of each substation site, assessing the risk (probability) of each threat manifesting, including prioritization of assets at the site and the identification of potential consequences and assessing the vulnerability of the site to the risks identified.

The North American Electric Reliability Corporation (NERC) classifies critical substations under its critical infrastructure protection plan (CIP) as; **NERC/CIP Critical Substations – substations that if significantly damaged will cause a major decrease in transmission system reliability**

The following is one example of a Threat Characterization Matrix for a Critical Transmission Substation:



Security Evaluation Prcoess - example - EAST SHORE - 7.8

Assault Team

Severity \ Exposure	1	2	3	4	5
1	2	3	4	5	6
2	3	4	5	6	7
3	4	5	6	7	8
4	5	6	7	8	9
5	6	7	8	9	10

SCORE: 7

Moderate Severity, Moderate Exsposure . Active overnight area

Maritime

Severity \ Exposure	1	2	3	4	5
1	2	3	4	5	6
2	3	4	5	6	7
3	4	5	6	7	8
4	5	6	7	8	9
5	6	7	8	9	10

SCORE: 10

High severity, High exposure due to Harbour traffic

Sabotage

Severity \ Exposure	1	2	3	4	5
1	2	3	4	5	6
2	3	4	5	6	7
3	4	5	6	7	8
4	5	6	7	8	9
5	6	7	8	9	10

SCORE: 7

Moderate Severity, Moderate exposure. Side Fence adjacent to public road

Standoff

Severity \ Exposure	1	2	3	4	5
1	2	3	4	5	6
2	3	4	5	6	7
3	4	5	6	7	8
4	5	6	7	8	9
5	6	7	8	9	10

SCORE: 7

Moderate Severity, moderate exposure, Large Yard mutilpe buildings

Theft/Diversion

Severity \ Exposure	1	2	3	4	5
1	2	3	4	5	6
2	3	4	5	6	7
3	4	5	6	7	8
4	5	6	7	8	9
5	6	7	8	9	10

SCORE: 7

Moderate Severity, moderate exposure

VBIED

Severity \ Exposure	1	2	3	4	5
1	2	3	4	5	6
2	3	4	5	6	7
3	4	5	6	7	8
4	5	6	7	8	9
5	6	7	8	9	10

SCORE: 9

High Severity, High Exposure due fence line close to distance Yard and Side Fence adjacent to public road

Figure 5 – Threat Characterization Matrix

Each substation owner can perform a threat analysis and ranking of NERC/CIP Critical Substations and determine the impact of a catastrophic physical attack on those substations.

Once this threat analysis and ranking is accomplished, the substation owner will generally try to identify the substation design, perimeter protection, security equipment/protocols and counter measures to effectively protect the substation from all perceived human-caused physical attacks.

GIS provides the substation owner with a pre-engineered substation design that enables the substation owner to employ construction methods for substations that reduce the impact of Human-Caused Physical Threats and enhance resiliency. GIS designs can expand the outermost Tier 3 layer of security by adding buffer distance in addition to strong wall/barriers. GIS designs also allow for more concentrated mid-layer Tier 2 and maximum innermost Tier 1 security.

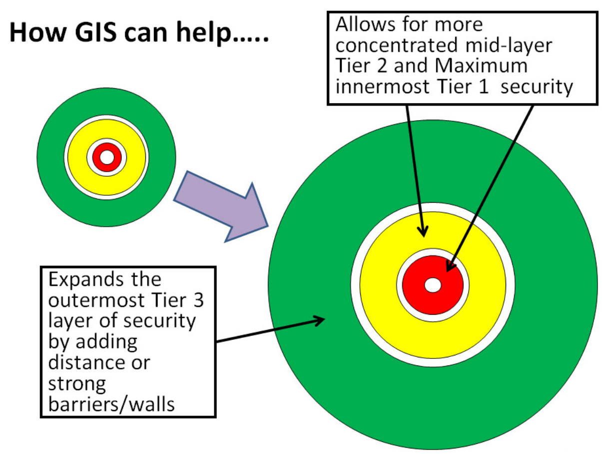


Figure 5 – GIS Enhanced Tier 2 and Tier 3 Security

Designing a substation that is truly immune to most human-caused physical threats is challenging. GIS designs in concert with GIS Enabled Construction Methods are an effective method to protect a substation and its associated electrical equipment from severe damage from a nefarious human-caused physical intentional attack. GIS designs allow for the following substation design attributes with respect to protection from nefarious human-caused physical intentional attack:

- Reduced area of the substation, flexible compact arrangements
- Reduced exposed perimeter of the substation, significantly reduced cost for perimeter protection
- Expanded Tier 3 security buffer, intruder neutralization devices can be more easily installed
    - More concentrated fixed cameras with analytics at the perimeter
    - More effective pan-tilt-zoom camera coverage with analytics
- Concentrated Tier 2 and Tier 1 security layers with less potential for penetration
    - More concentrated thermal imaging cameras with analytics
- "Out of sight, out of mind" to blend into surroundings and hidden from aerial imagery
- No line-of-site to equipment for projectile weapons
- Switchgear is completely enclosed with fire protection
- Transformers and reactors can be enclosed and covered with grating overhead to minimize air assault
- Relay control rooms can be located at the interior of the complex to enhance protection
- Interfaces to transmission and distribution system can be more easily concealed underground

Figure 5 – Traditional AIS versus Resiliency Enhanced GIS

Figure 6 – GIS Substation, Resiliency Enhanced Against Both Naturally and Human-Caused Physical Threats

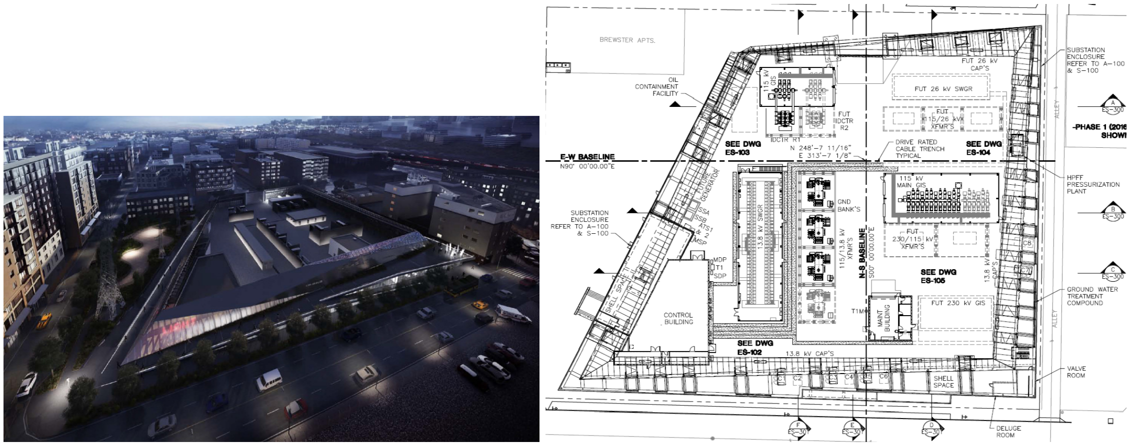


Figure 7 – GIS Substation, Resiliency Enhanced Against Both Naturally and Human-Caused Physical Threats

The use of gas insulated substation designs is a cost-effective strategy that results in enhanced resiliency and higher reliability due to a reduction in substation area and exposure to external threats.

RESPOND AND RECOVER

Damage assessment and the rapid implementation of recovery steps are essential to minimizing the impact to the electric system caused by damage to a critical substation. Innovative substation solutions can reduce restoration times after storm events or physical attacks. GIS solutions can provide options for substation owners during the process of repairing substations that are damaged.

Mobile GIS designs offer a wide range of switchgear and bus configurations at all operating voltages. These mobile GIS options can be designed to be located on a single trailer or multiple trailers and connected via power cables in any required line or bus configuration.

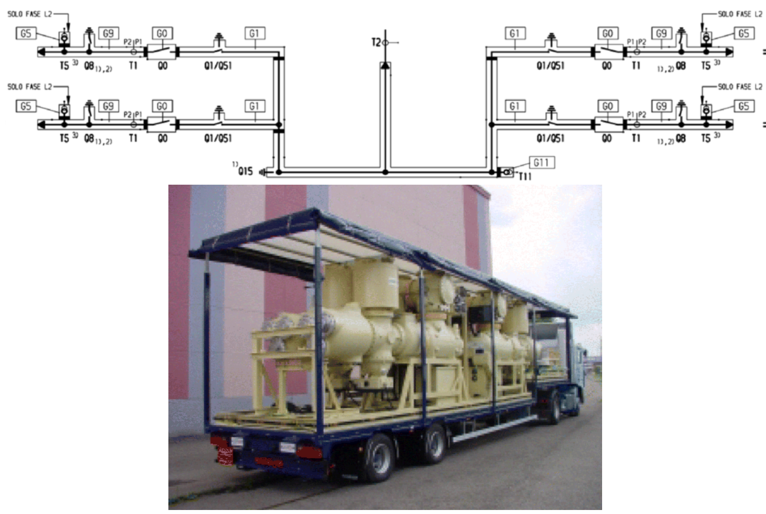


Figure 8 – Mobile GIS Trailer

The installation of mobile GIS to temporarily replace existing switching equipment that has been damaged can significantly expedite the process of repairing and exchanging damaged AIS equipment or GIS components/modules. The rapid reestablishment “fast re-energization” of service that mobile GIS provides, further enhances the resiliency of the substation and the transmission system.

Mobile GIS equipment can also be used to provide complete temporary substation switching arrangements as a proactive solution for the following scenarios:

- Critical loads that develop in short time periods
- By-passes for transmission switching equipment during repairs or maintenance
- Major storm restoration options
- Temporary switching arrangements to aid in expediting construction of substations and lines
- A “ready backup” for critical infrastructure facilities (i.e. government and public services)

All of these benefits contribute to the overall resiliency of individual substations as well as the resiliency of the transmission system.

CONCLUSIONS

The use of gas insulated substation designs is an effective method to protect a substation its associated electrical equipment from severe damage from a naturally occurring catastrophic event or a nefarious human-caused physical intentional attack.

The use of gas insulated substation designs is a cost-effective strategy that results in enhanced substation resiliency and higher reliability due to a reduction in substation area, perimeter, the ability to shield equipment and minimized exposure to external threats.

The benefits employing GIS designs in concert with GIS Enabled Construction Methods for use as a hardening tool and a response /recovery tool for substations, contributes to the overall resiliency of the transmission system.

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