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Jan 20, 2014

MEDIUM VOLTAGE GAS INSULATED SWITCHGEAR
By Sharif Ahmed of Siemens Canada Senior Member IEEE
GIS

Gas Insulated Switchgear

MV Switchgear since 1950’s

Air-insulated  Air/solid-insulated  Cast-resin-insulated
What is SF6

Its Sulphur Hexafluoride

SF6 Gas

Sulphur Hexafluoride is a colourless, odourless, chemically neutral, and inert gas, non-inflammable and 5 times heavier than air, not toxic and not ozone depleting.
Is SF6 a Health Hazard

Pure SF6 is physiologically completely harmless for humans and animals; it’s even used in medical diagnostic. Due to its weight it might displace the oxygen in the air, if large quantities are concentrating in deeper and non ventilated places.

Legislation for chemicals does not categorise SF6 as a hazardous material.

Is SF6 harmful for the environment?

It has no ecotoxic potential, it does not deplete ozone. Due to its high global warming potential it may contribute to the man made greenhouse-effect, if it is released into the atmosphere. However in electrical switchgear the SF6 gas is always used in gas-tight compartments, greatly minimising leakage. This make the real impact on greenhouse effect negligible.
SF6 Gas Insulated Switchgear

- **What is Gas Insulated Switchgear**
- **The Switchgear where SF6 Gas is the insulating medium.**
- **Why this Gas is chosen for insulation medium?**
- **Lets see the characteristics of SF6 gas**

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**Characteristics of SF6 Gas**

- Non-poisonous, non-flammable, inert, self-restoring insulation
- Dielectric strength 6x better than air
- Low current arcs are self-extinguishing
- $\text{SF}_6$ only insulates – not used for interrupting, therefore, no arcing by-products.
- No oxidation inside of enclosure
- Gas leakage rate < 0.1% annually

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What is Medium Voltage Vacuum GIS?

- Gas Insulated Switchgear where the insulation Medium is SF6
  - Low pressure SF6 used as an insulating medium for all primary components
- Because of the SF6 under pressure Dielectric strength is 6x better than air
- With a higher Insulation the distances between the live parts and earth are reduced.
- Because of the reduced clearances between the live parts the size of the Switchgear is reduced and you get a much smaller footprint of the Gear.
- Vacuum interrupter technology is used in GIS Gears
- Circuit Breakers are fixed mounted in GIS Gears

Primary components are virtually maintenance-free due to controlled gas environment

SF6 for lightning withstand level is up to 200 kV BIL at 38 kV

Integral disconnecting is by the use of a three position selector switch: - Connected, Disconnected & Ground Positions

The Vacuum interrupters used are good for up to 30,000 normal operations and 50 fault operations.

Make-proof earthing by means of the vacuum circuit-breaker

Hermetically bolted / Sealed switchgear housings

Cable connections are with inside-cone plug-in system, or for connection of gas-insulated and solid-insulated bars

Very small footprints
Gas Insulated Switchgear

Three phase encapsulation

Single Phase encapsulation
(W600mmxD1625mmxH2350mm)

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Key Features – MV Vacuum GIS

Offers high reliability

Offers high flexibility through modular design
Offers high safety by Inherently Arc Resistance iso phase design

Features small foot print design for total cost savings

Increased immunity to the surrounding environments

Maximizes revenue and profit by low maintenance

Delivers low a total cost/risk of ownership over product life cycle

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Arc Resistant

Arc Resistant AS PER ANSI
• ANSI 37.20.7-2007

For Major Operational Activities, Reduced Level Of PPE Can Be Used For MV GIS

<table>
<thead>
<tr>
<th>Activity</th>
<th>MV Air-Insulated Switchgear (AIS) 1</th>
<th>MV GIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open/close circuit breaker</td>
<td>HRC 2 (door closed) 2</td>
<td>HRC 0</td>
</tr>
<tr>
<td></td>
<td>HRC 4 (door open)</td>
<td></td>
</tr>
<tr>
<td>Isolate circuit</td>
<td>HRC 4 (racking, door open or closed) (Note: isolation in metal-clad requires racking to test or disconnect position)</td>
<td>HRC 0 (operation of three-position switch to open position)</td>
</tr>
<tr>
<td>Application of safety grounds</td>
<td>HRC 4</td>
<td>HRC 0</td>
</tr>
</tbody>
</table>
## Technical Data

<table>
<thead>
<tr>
<th></th>
<th>IEC</th>
<th>IEC</th>
<th>ANSI</th>
<th>IEC</th>
<th>ANSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Voltage (kV)</td>
<td>7.2</td>
<td>12</td>
<td>15</td>
<td>17.5</td>
<td>24</td>
</tr>
<tr>
<td>Rated Power Frequency Withstand Voltage (kV)</td>
<td>20</td>
<td>28</td>
<td>36</td>
<td>38</td>
<td>50</td>
</tr>
<tr>
<td>Rated Lightning Impulse Withstand Voltage (kV)</td>
<td>60</td>
<td>75</td>
<td>95</td>
<td>95</td>
<td>125</td>
</tr>
<tr>
<td>Rated Short Circuit Breaker Current* (kA)</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Rated Short Time Current 3 Sec* (kA)</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Rated Short Circuit Making Current* (kA)</td>
<td>104</td>
<td>104</td>
<td>104</td>
<td>104</td>
<td>104</td>
</tr>
<tr>
<td>Rated Busbar Current* (A)</td>
<td>5000</td>
<td>5000</td>
<td>5000</td>
<td>5000</td>
<td>5000</td>
</tr>
<tr>
<td>Maximum Circuit Breaker Rating* (A)</td>
<td>4000</td>
<td>4000</td>
<td>4000</td>
<td>4000</td>
<td>4000</td>
</tr>
</tbody>
</table>

* Maximum

## Main Applications for Medium-Voltage Switchgear

- **Generation level and high-voltage system**
- **Primary distribution level**
- **Secondary distribution level**
- **Low voltage**
Situation with Gas-Insulated Switchgear

Today’s state of the art is gas-insulated switchgear with the following main benefits:

- Small, compact dimensions
- Independent of environmental effects and climate
- Widely maintenance-free
- Maximum safety for staff
- Low fire risk
- Arc-fault tested

Advantages:

- Low invest for buildings due to compact dimensions and climate-independent design
- Maximized power supply reliability
- Maximum personal safety
- Lowest life cycle costs
- Reduced operational costs
Maximum Security of Operation

Separate compartments for busbar and circuit-breaker offer a maximum degree of availability

- Busbar (in operation)
  Attention: High voltage

- Feeder earthed (earthing)

- Circuit-breaker
  Access without danger to current transformer, feeder voltage transformer, cable plugs, operating mechanisms

Busbar Design

- Busbar housing
- Three-position switch
- Pole housing

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Busbars of higher ratings upto 5000A

Twin busbar housing

Three-position switch

Pole housing

Single Busbar Switchgear:
Cross Section of Single Pole

1 Cast aluminum Alloy housing
2 Busbar with sliding supports
3 Three-position selector switch
4 Gas tight bushing
5 Vacuum Interrupter
6 Toroidal-core current transformer
7 Capacitive voltage sensor
8 Shock-proof cable termination
Vacuum interrupter mounted in Circuit Breaker pole housing

Cast Resin Bushing separating Gas Chambers

- Routine tests including:
  - X-ray test
  - High voltage test (HV)
  - Partial discharge test (PD)
  - Helium leak test
Rated peak and/or making current

$$I_p = \kappa \cdot \sqrt{2} \cdot I_k$$

IEEE: \(I_{ma} \text{ or } I_p = 2,6 \cdot I_k \text{ at } 60 \text{ Hz}\)

IEC: \(I_{ma} \text{ or } I_p = 2,5 \cdot I_k \text{ at } 50 \text{ Hz}\)

\(2,6 \cdot I_k \text{ at } 60 \text{ Hz}\)

\(2,7 \cdot I_k \text{ at } 50 \text{ Hz} \text{ if ratio } X/R > 14 \text{ (i.e. } \tau > 45 \text{ ms)}\)
Interrupters used in GIS

- The interrupters used are designed for 30,000 normal operations.
- 50 Fault operations
- The Breakers are normally operated at 5 cycle
- The Breakers can also be operated at 3 cycles if requested by the client.
- The symmetric value of short circuit current is 40kA.
- Max making current 104kA which is asymmetric value of current.
- The short circuit ratings offered by different manufactures are 25kA, 31.5kA and 40kA.
Manometer for checking Gas pressure

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- Gas pressure manometers arranged at the switchgear front
- Gas pressure can be read with security even without auxiliary voltage supply
- Optionally with independent of ambient temperatures
- Optionally with independent of site altitude
- With two signalling contacts for “gas pressure too low and gas pressure too high” indication
- Optionally with three signalling contacts for “gas pressure too low / very low” and “gas pressure too high” indication

Three Position Selector Switch

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Viewport for Three Position Switch

Three Position Selector Switch View by Camera

Web cam designed Cameras outside of the gas chambers with plug and play Fire wire /USB2.0 Connections to any laptop

Design via Video Cameras
View Port via Video Camera
For Disconnector and Grounding Switches

Three Position Switch

Three Position Selector Switch

Circuit
CLOSED

Circuit
OFF

Circuit Ready
for Grounding

Circuit
Grounded
Feeder Earthing with the Circuit-Breaker

1) Close the “earthing switch” of the three-position switch
   - Ready to earth
   - Electrical OFF-signals are suppressed
2) Close the circuit-breaker
    - Feeder earthed
3) Padlock the “feeder earthed” interlock
   - The circuit-breaker is blocked mechanically
   - Signalling contact: Feeder earthed (option)

Lock out Tag out
Operation of Three Position Switch

- Switch position indicator
- Disconnectorswitch
- Operating shaft
- Disconnectorswitch
- Switch position indicator
- Circuit-breaker switch
- Operating shaft
- Earthing switch

Operation of a Single Phase Encapsulated GIS

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Operation of a Single Phase Encapsulated GIS

Circuit Breaker operating mechanism
Operating Tools

Interlocks (Selection)

Interlocks are designed according to IEC 62 271-200

Standard interlocks

- Three-position disconnector against circuit-breaker – mechanical
- Disconnector against earthing switch (within three-position disconnector) – mechanical
- Locking device at the circuit-breaker switch
- Locking device at the three-position disconnector switch

Additional interlocks

- Electromagnetic interlock at the three-position switch / disconnector switch
- Electromagnetic interlock at the three-position switch / earthing switch
Current Measurement
Toroidal (Window) Type Current Transformer

- Conducting paths form the primary winding, free from dielectric and thermal stress
- Secondary components outside enclosure and easily accessible
- No dielectric stress on cast resin components

Current Measurement

Ring-core current transformers:
- Main circuit as primary part without dielectric and thermal problems
- Secondary part accessible outside the enclosure without hazard
- Free of dielectrically stressed cast-resin parts.
**Fused Busbar Voltage Transformer**

- Single-pole insulated
- $\text{SF}_6$ filled gas switch compartment
- Protection of busbar by gas-tight barriers
- Safely removal using ground switch
- Fused and disconnectable

**Line Side (Cable Side) Voltage Transformer**

- Plugged-in panel connection
- Metal-enclosed
- Either plugged-in directly or mounted separately and connected via a plug-in cable
- Completely shockproof
- Outside main circuit
Line-Side (Cable-Side) Voltage Transformer

- Plugged-in panel connection
- Mounted separately and connected via a plug-in cable
- Grounded Metal-enclosed
- Wye/Wye connected
- 100% shock proof
- Outside main circuit.

Capacitive voltage indication

- Coupling electrode built into the pole-support plate of the circuit breaker
- For checking for dead state of each pole
**Low-Voltage Compartment**

- **Height:** 850 mm
  1200 mm (option)
- Removable, bus wires and control cables plugged in (via 6 or 10-pole coded module plug connectors)
- Panel control via conventional control devices or digital bay controller
- Customer-specific equipment (protection, control, metering, annunciation)
- Wiring in H07VK, optionally also heat-resistant and halogen-free

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**Plug-in Cable termination system**
Various multiple cable terminations

Single Cable Plug-in

2 or 3 Cables per Phase with Plug Size 3

6 Cables per Phase With Plug Size 1 to 3

Termination for Tubular Gas Bar

Surge Arresters

Termination for Solid-Insulated Bar

Plug-in cable termination system

- Inner-cone system acc. DIN 47637
- Metal-enclosed, all-insulated
- Dead front
- Integrated capacitive voltage tap for checking for dead state
**Cable connector**

![Cable connector](image1)

**Dummy connector**

![Dummy connector](image2)

<table>
<thead>
<tr>
<th>No.</th>
<th>Size</th>
<th>Max. operating voltage</th>
<th>Packing unit</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>827150003</td>
<td>2</td>
<td>42</td>
<td>aboveground</td>
<td>0.6</td>
</tr>
</tbody>
</table>

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Cable connections in GIS

25kV AIS Line-up
Physical Dimensions & Number of Cells of AIS

25kV GIS for same Switchgear
**Number of Cells and dimensions for GIS**

![GIS Diagram]

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**A Closer Look at GIS vs AIS**

GIS
- Requires 20% of space needed for air-insulated designs

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Switchgear Size Comparison between 38 kV AIS and GIS

Outdoor Open Type Circuit Breakers

Air Insulated Switchgear

GIS Insulated Switchgear

Space problem? Go for GIS

I have to double the substation MVA, but don’t have the space?
**Lightning impulse withstand voltage with gas leakage,**

![Graph showing the relationship between SF₆/air mixture and lightning impulse withstand voltage with gas leakage.]

**AIS VS GIS**

*Advantages of using 35kV GIS in comparison to 35kV AIS*

**Switchgear Dimensions**

**AIS**
- Width: 1500mm
- Depth: 2400mm
- Area per Section ≈ 3.6m²
- Operating Aisle ≈ 1.5m
- Example with 10 sections:
  - Area required AIS ≈ 36 m²
  - Operating Aisle ≈ 23m²

**GIS**
- Width: 800mm
- Depth: 1625mm
- Area per Section ≈ 1m²
- Operating Aisle ≈ 0.8m
- Example with 10 sections:
  - Area required AIS ≈ 10m²
  - Operating Aisle ≈ 5m²
ADVANTAGES OF GIS

AIS
AIS maintenance will be be required after 5 years of service. Maintenance means:
• Switch off of lines, feeder and busbars
• Grounding
• All CB’s in test position
• Test function of CB's and all other switching devices
• Remove the draw out section and dismantle panels partly in order to get access to busbars and cable sections

GIS
GIS maintenance will required after 5 years Maintenance means:
Visual Inspection

AIS MAINTENANCE

• Clean the panels from dust
• Lubricate all bearings and surfaces
• Check panel function and put board back into service
• Estimated time per panel: 4 hours
• Estimated cost per hour: US$ 100
• For 10 panels:
• Estimated time : 1 week
• Estimated cost : US$ 4000
• Shutdown time for customer process machines is not considered
## AIS VS GIS

**Advantages using MV GIS in comparison to MV AIS**

### Availability

<table>
<thead>
<tr>
<th>AIS</th>
<th>GIS</th>
</tr>
</thead>
</table>
| During maintenance period, the switchgear is out of service.  
  • Provisions for alternative supply routes must exist.  
  • Switching over procedures need to be followed  
  • After maintenance original conditions need to be established | GIS S/G is maintenance free  
  - No human errors can occur due to hermatically sealed isolation. Therefore peace of mind for customer will be ensured. |

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## ADVANTAGES OF GIS IN COMPARISON TO AIS

Following risks have to be taken into account by using AIS switchgear:

- Switching failures
- Disturbances in the network may appear
- Human errors may occur due to left tools, loose connections, unscrewed bolts, unfixed covers etc. Therefore the risk of failures inside the switchgear (arc fault) is very high.
### ADVANTAGES OF GIS IN COMPARISON TO AIS

#### Environmental Aspects

<table>
<thead>
<tr>
<th>AIS</th>
<th>GIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Influence of dust, humidity and vermin to all active parts as busbars, breakers, cable connections:</td>
<td>No environmental influence to maintenance free, Hermatically sealed S/G.</td>
</tr>
<tr>
<td>Need of maintenance, sequence depending from environmental influence</td>
<td>Busbars are single pole gas insulated and probability of internal faults are substantially reduced and flash over between phases is not possible</td>
</tr>
<tr>
<td>• By high humidity hygrometer and or heaters in cable compartment is necessary. Therefore additional costs and control is necessary</td>
<td>No influence of insulation level. Peace of mind.</td>
</tr>
<tr>
<td>• By vermin’s, special measurements in building, cable compartments, switchgears, such as alarming, shielding etc. are necessary.</td>
<td></td>
</tr>
</tbody>
</table>

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### Environmental Problems

- Dust?
- Salt?
- Moisture?
- Corrosive gases?
- Mice?
- Rats?
- Cats?
- Squirrels?
- Snakes?
- Altitude?

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### ADVANTAGES OF GIS IN COMPARISON TO AIS

<table>
<thead>
<tr>
<th>AIS</th>
<th>GIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Therefore additional costs and control is necessary. Flash over between phases are possible and busbar differential protection may be required. Influence of altitude: With increase of the altitude, the insulating capacity of insulation in air decreases due to the decreasing air density. Depending on the altitude a correction factor has to be taken into account.</td>
<td>No influence of altitude on insulation level.</td>
</tr>
</tbody>
</table>

**Spare Parts**

<table>
<thead>
<tr>
<th>AIS</th>
<th>GIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>For an estimated live time of 30 years the following spares have to be taken into account by using AIS technology: Lubricants, screws, bolds, nuts, contact fingers for draw out unit Isolators, bushings Therefore additional cost for spares and storage room will arise for the customer. Further more staff for exchange the parts have to be provided.</td>
<td>No spares for high voltage portion are required no additional cost for spares &amp; storage.</td>
</tr>
</tbody>
</table>
Reliability

AIS

By using AIS switchgear, risks of failures due to human error, maintenance, environmental aspects and switching in network will appear.

GIS

None of the AIS mentioned risk factors will appear by using GIS equipment. Therefore GIS switchgear has a much more higher contrast to AIS Switchgear.

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10 year life cycle cost for AIS versus GIS switchgear

<table>
<thead>
<tr>
<th>Description</th>
<th>Frequency in 10 years (AIS)</th>
<th>Duration (days)/Qty</th>
<th>Cost</th>
<th>AIS</th>
<th>GIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor substation</td>
<td></td>
<td></td>
<td>A</td>
<td>A+</td>
<td></td>
</tr>
<tr>
<td>Arc Resistance</td>
<td></td>
<td></td>
<td>B</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Real Estate</td>
<td>40' X 18' vs. 21' X 10'</td>
<td>$/ sqf</td>
<td>C</td>
<td>C-</td>
<td></td>
</tr>
<tr>
<td>Installation at site</td>
<td>crane vs. forklift /manhours</td>
<td></td>
<td>D</td>
<td>D-</td>
<td></td>
</tr>
<tr>
<td>Spare breaker</td>
<td>1</td>
<td>S</td>
<td>E</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Grounding Device</td>
<td></td>
<td></td>
<td>F</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Routine Maintenance Interval</td>
<td>3</td>
<td>S</td>
<td>E</td>
<td>E-</td>
<td></td>
</tr>
<tr>
<td>Suits according to NFPA 70E</td>
<td></td>
<td></td>
<td>F</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Outage maintenance</td>
<td>1</td>
<td>S</td>
<td>G</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Lost of production</td>
<td>priceless</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No phase to phase fault</td>
<td>priceless</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>H</td>
<td></td>
<td>H -25% cheaper</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Indoor Substation 27kV, 31.5kA, 1200A - Typical 10 section lineup with 2 mains, 1 tie, and 7 feeder breakers

** Arc flash suits required when racking non-arc resistance equipment above 1000 volts
Customer Benefits

- Environmental Independence
- Compactness
- Maintenance-free Design
- Personal Safety
- Security of Operation, Reliability
- Economy, Ecology

General Information

The gas-insulated switchgear is for application in nearly all branches like:-

<table>
<thead>
<tr>
<th>Airports &amp; Ports</th>
<th>Automotive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buildings</td>
<td></td>
</tr>
<tr>
<td>Cement Industries</td>
<td>Chemicals &amp; Pharma</td>
</tr>
<tr>
<td>Food &amp; Beverage</td>
<td>General Industries</td>
</tr>
<tr>
<td>Offshore Industries</td>
<td>Oil &amp; Gas</td>
</tr>
<tr>
<td>Semicondor</td>
<td>Steel &amp; Aluminium Industries</td>
</tr>
<tr>
<td>Transportation &amp; Railway</td>
<td>Water</td>
</tr>
<tr>
<td></td>
<td>Utilities</td>
</tr>
<tr>
<td></td>
<td>Windfarms</td>
</tr>
</tbody>
</table>
GIS is used in the following Industry

- Transportation Systems
- Wind Farms Offshore
- Mining
- Steel and Aluminium Industry
- Oil - Offshore
- Utilities

GIS is used in the following Industry

- Tourism & Hotels
- Paper
- Chemical
- Oil & Gas
- Automotive
- Food & Beverage
- Airports & Airlines
GIS Market environment

- **Market Trend**

<table>
<thead>
<tr>
<th>Year</th>
<th>GIS</th>
<th>AIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>20%</td>
<td>80%</td>
</tr>
<tr>
<td>2007</td>
<td>27%</td>
<td>73%</td>
</tr>
</tbody>
</table>

  - CAGR +4.5%
  - CAGR +6%

  **outlook**

  - GIS High developed market
  - Emerging GIS market
  - White spots for GIS

---

**Thanks**

Thank you for your attention

**Questions?**