IEEE PES
Power & Energy Society

Jornada técnica en subestaciones

Gas Insulated Switchgear & Transmission Lines

Hermann Koch IEEE Fellow – Siemens

Febrero 20 HMV Ingenieros, Medellin, 8 am – 5pm

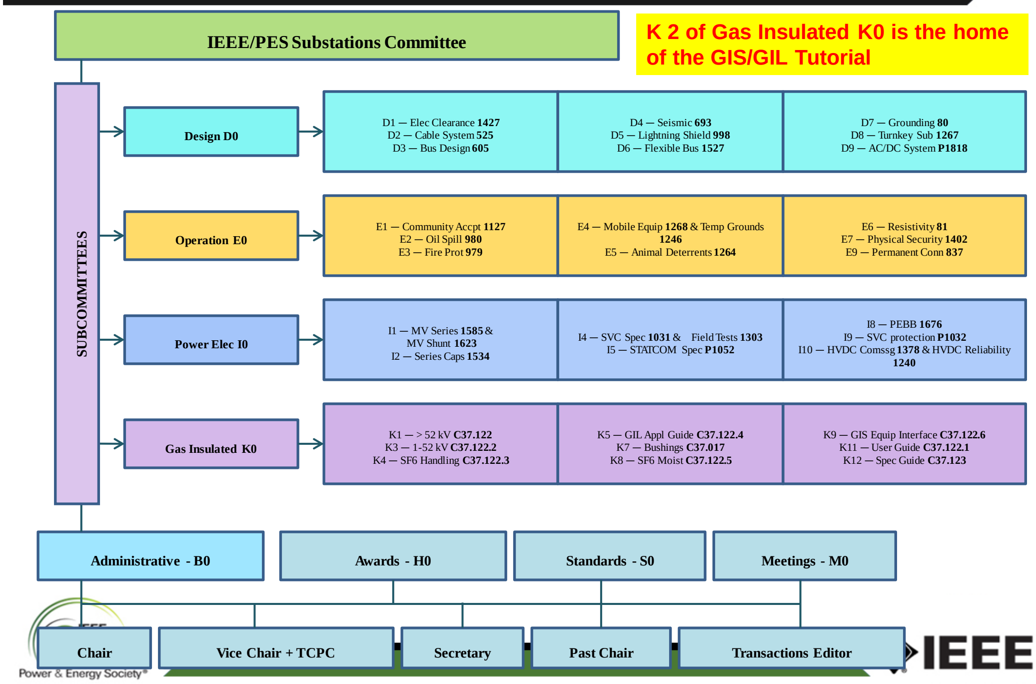
Agenda

Part 1

08:30	Introduction & Theory
08:45	Design& Manufacturing
09:00	Testing, Operation & Maintenance
09:15	Interface to GIS
09:30	Control and Monitoring
09:45	Installation & Commissioning
10:15	Coffee Break

Part 2

13:00	GIS Applications
13:20	Life Cycle Cost
13:40	Compare AIS and GIS
14:00	Mobile GIS
14:20	GIS Specification
14:40	GIL
15:00	Future Development of HV GIS
15:45	Coffee Break

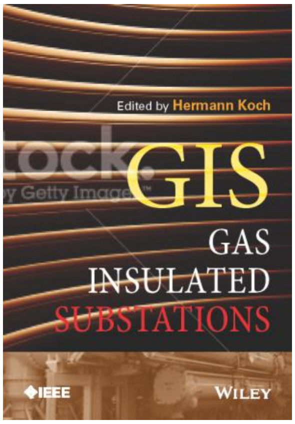


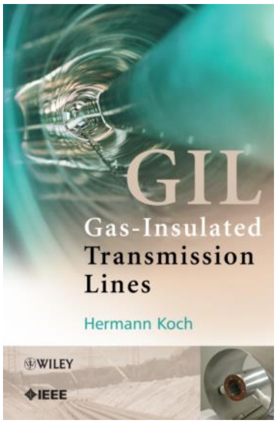
K2 Gas Insulated Technology Tutorial / Panel Active Members

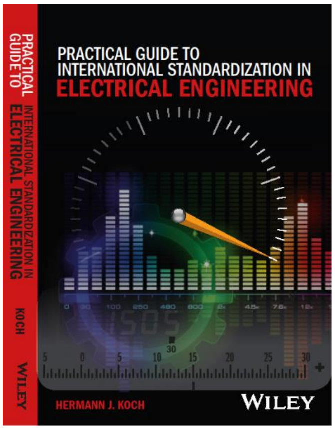
Name	Affiliation	Time .
George Becker	POWER Engineers	since 2002
Arnaud Ficheux	GE Grid Solutions	since 2008
John Brunke	POWER Engineers	since 2005
Mark Etter	ABB	since 2002
Pat Fitzgerald	AZZ CGIT	since 2006
Hermann Koch	Siemens	since 2002
Ryan Stone	Mitsubishi	since 2006
Peter Grossmann	Siemens	since 2008
Dave Solhtalab	PG&E	since 2010
Richard Jones	EnEngineering/SES	since 2002
Pravakar Samanta	ABB	since 2014
Sean Parsi	kinectrics	since 2014
Dave Mitchell	Dominion	since 2014
Michael Novev	Burns & McDonnell	since 2014

K2 Gas Insulated Technology Tutorial / Panel Past Members

Name	Affiliation	Date .
Arun Arora	Consultant	2002 to 2014
Lutz Boettger	ABB	2002 to 2006
Hugues Bosia	AREVA	2002 to 2007
Wolfgang Degen	Consultant	2002 to 2008
Mel Hopkins	CGIT	2002 to 2005
Deborah Ottinger	EPA	2005 to 2007
Venkatesh Minisandram	National Grid	2002 to 2010
Joseph Pannunzio	AREVA	2009 to 2010
Charles Hand	SCE	2010 to 2015
Phil Bolin	Mitsubishi	2002 to 2015







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IEEE GIS-GIL References Standards

C37.122	Standard for High Voltage Gas-Insulated Substations, rated above 52 kV
C37.122.1	GIS User Guide
C37.122.2	Guide for Application of Gas-Insulated Substations (GIS) 1 kV up to 52 kV
C37.122.3	SF6-Handling
C37.122.4	Application and User Guide for Gas-Insulated Transmission Lines (GIL), Rated 72.5 kV and Above
C37.122.5	SF6 Moisture Guide
C37.122.6	GIS Equipment Interfaces
C37.017	Revision of Standard for Bushing for High Voltage (over 1000 V AC) Circuit Breakers and Gas Insulated Switchgear
C37.123	Guide to Specification for GIS Electric Power Substation Equipment

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IEC GIS-GIL References Standards

IEC 62271-3:2015	High-voltage switchgear and controlgear - Part 3: Digital interfaces based on IEC 61850
IEC 62271-200:2011	High-voltage switchgear and controlgear - Part 200: AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV
IEC 62271-201:2014	High-voltage switchgear and controlgear - Part 201: AC solid-insulation enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV
IEC 62271-202:2014	High-voltage switchgear and controlgear - Part 202: High-voltage/ low-voltage prefabricated substation
IEC 62271-203:2011	High-voltage switchgear and controlgear - Part 203: Gas-insulated metal-enclosed switchgear for rated voltages above 52 kV
IEC 62271-204:2011	High-voltage switchgear and controlgear - Part 204: Rigid gas-insulated transmission lines for rated voltage above 52 kV
IEC 62271-205:2008	High-voltage switchgear and controlgear - Part 205: Compact switchgear assemblies for rated voltages above 52 kV
IEC 62271-206:2011	High-voltage switchgear and controlgear - Part 206: Voltage presence indicating systems for rated voltages above 1 kV and up to and including 52 kV

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IEC GIS-GIL References Standards

IEC 62271-207:2012	High-voltage switchgear and controlgear - Part 207: Seismic qualification for gas-insulated switchgear assemblies for rated voltages above 52 kV
IEC TR 62271-208:2009	High-voltage switchgear and controlgear - Part 208: Methods to quantify the steady state, power-frequency electromagnetic fields generated by HV switchgear assemblies and HV/LV prefabricated substations
IEC 62271-209:2007	High-voltage switchgear and controlgear - Part 209: Cable connections for gas-insulated metal-enclosed switchgear for rated voltages above 52 kV - Fluid-filled and extruded insulation cables - Fluid-filled and dry-type cable-terminations
IEC TS 62271-210:2013	High-voltage switchgear and controlgear - Part 210: Seismic qualification for metal enclosed and solid-insulation enclosed switchgear and controlgear assemblies for rated voltages above 1 kV and up to and including 52 kV
IEC 62271-211:2014	High-voltage switchgear and controlgear - Part 211: Direct connection between power transformers and gas-insulated metal-enclosed switchgear for rated voltages above 52 kV
IEC TS 62271-304:2008	High-voltage switchgear and controlgear - Part 304: Design classes for indoor enclosed switchgear and controlgear for rated voltages above 1 kV up to and includuing 52 kV to be used in severe climatic conditions

GIS Basic Ratings of GIS

according to IEEE C37.122 and IEC 62271-203

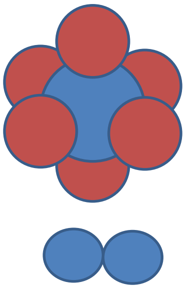
Rated Maximum High Voltages	(U_m) [kV]	66-72,5-100-123-145-170-245 300-362-420-550-800-1100
Rated Insulation Levels	(U_p) [kV]	140-185-230-325-375-425 460-500-650-740-900-1200
IEEE Rated Lightning Impulse Withstand Voltage Levels	(U_p) [kV]	325-450-550-650-750-1050-1175-1425-1550-2100
Rated Currents	(I_R) [A]	up to 170 kV: 1250 A-3150 A above 170 kV: 3150 A-8000 A
Short Time Withstand Current	(I_C) [kA]	up to 170 kV: 16 kA-50 kA above 170 kV: 31,5 kA-100 kA
Rated Supply Voltage	(V)	DC: 48 V, 110 V, 125 V AC: 208/130 V, 400/230 V, 230/115 V

Content
Part 1

- **Theory**
- **SF_6 Insulating Gas**

Sulfur Hexafluoride SF_6

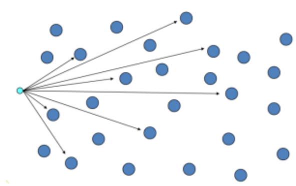
- A man-made colorless, odorless, stable gas
- A large octahedral non-polar molecule
- Collision Diameter
  - N_2 16.1 A
  - SF_6 36.5 A
- Molecular weight 146.05 (about 5 times the weight of air)
- SF_6 is broken down by heat and arcs
  - SF_6 bi-products largely reform into SF_6
- Ionization potential of Nitrogen 15.6 eV
- Ionization potential of SF_6 15.6 eV
- Pictured: SF_6 and N_2



Physics Review

- Ionization, the process of removing an electron from an atom or molecule
- Excitation, the condition in which an electron moves to a higher, unstable energy level. Relaxation results in the electron returning to a stable energy level, releasing the excess energy as a photon
- Free electrons
  - From ionization by cosmic rays, photons, friction, chemical reactions, thermal, etc.
- Mean free path
  - Mean distance before a molecule or electron will impact another molecule

- Mean Free Path
  - N_2 6×10^{-8} m
  - SF_6 2.5×10^{-8} m



GIS Theory

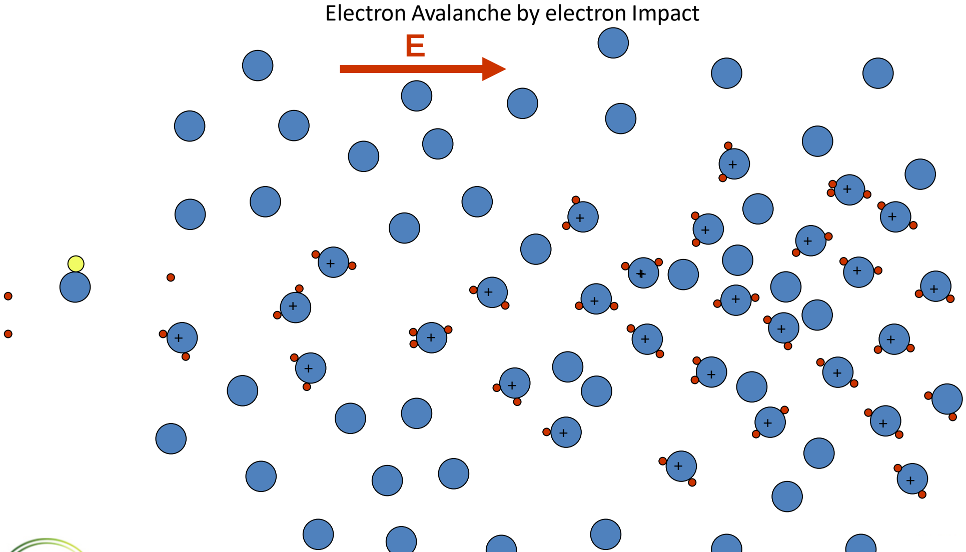
Non-homogeneous gap

Free electrons repelled from negative rod

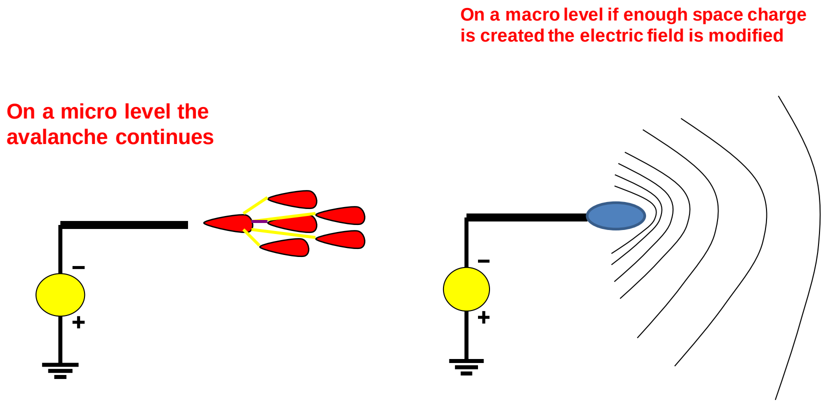
Ions Vs Electrons
Ion Mobility

- Mass ratio of an electron vs. mass of SF_6 1 to 125,000 (1500 lbs. vs 95,000 tons)

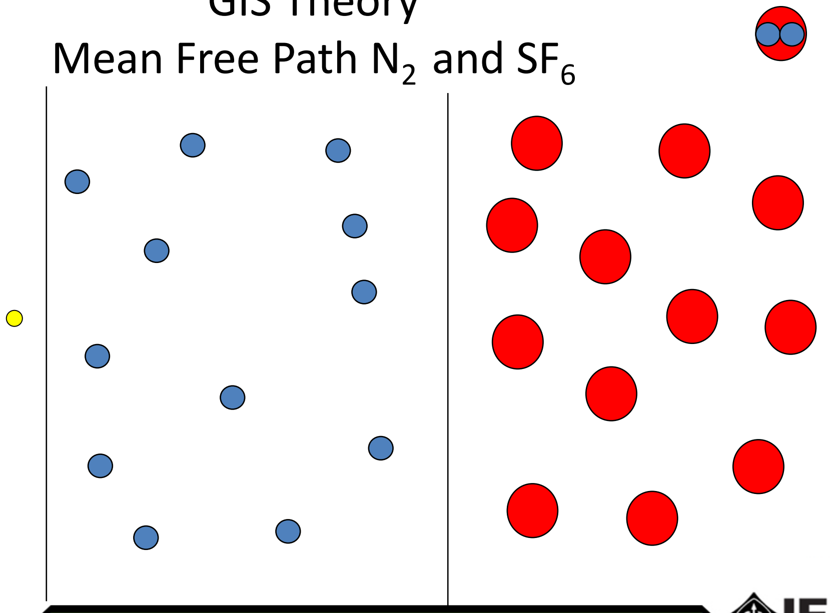
GIS Theory
Electron Avalanche by electron Impact



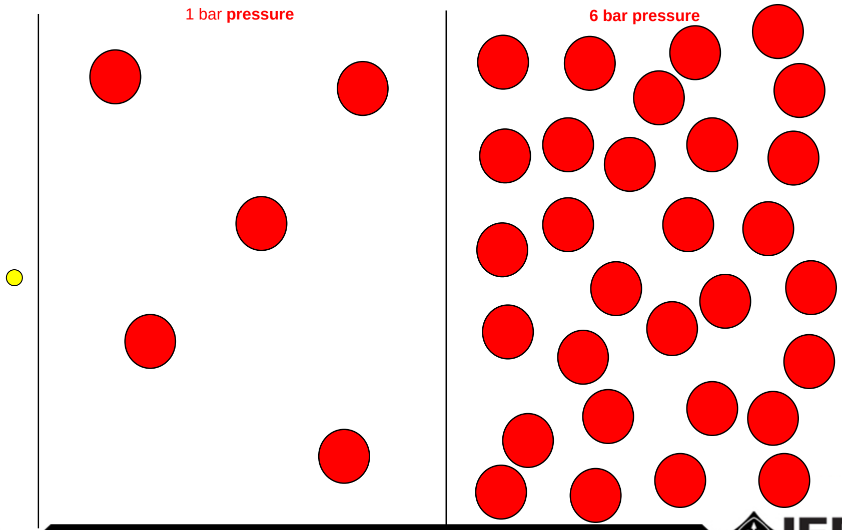
GIS Theory
Many Collisions Produce Photons and Photo Ionizations



GIS Theory
Mean Free Path N_2 and SF_6



GIS Theory
Impact of Increasing the Gas Density 6x



GIS Theory
Electron Affinity

- **Electro-negative**
  - Electron Affinity (strong affinity for electron attachment)
  - Free electrons are often captured
- **Mechanisms**
  - Resonance capture $$e + SF_6 \rightarrow SF_6^-$$
  - Dissociative attachment $$e + SF_6 \rightarrow SF_5^- + F$$
  - Energy requirements are low (0.1 eV or less)

GIS Theory
Summary, why is SF6 a Good Insulating Gas?

- Molecule is large
- Electron Affinity
- Fairly high ionization potential

•The breakdown strength of air is dramatically increased by the addition of small quantities of SF_6. In contrast, air has only a limited influence on the breakdown strength of sulfur hexafluoride. The addition of 10 % of air by volume reduces the breakdown voltage of SF6 by about 3 %, the addition of 30 % air by about 10 %.

Introducing Gas Insulated Substation

AIS

Up to 80% space saving

GIS

Protected against environmental influences

Higher reliability

Higher equipment costs

Less maintenance

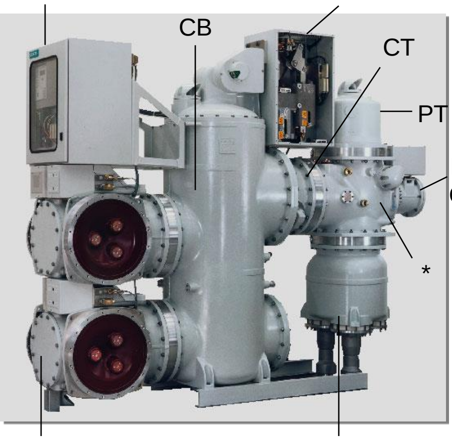
Better safety for personnel

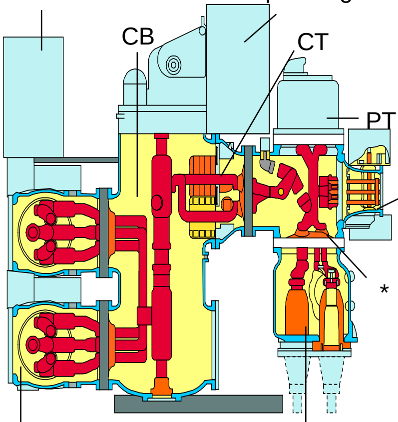
Longer operating life (> 50 years)

Content
Part 1

- **Design**
- **Modular Structure**

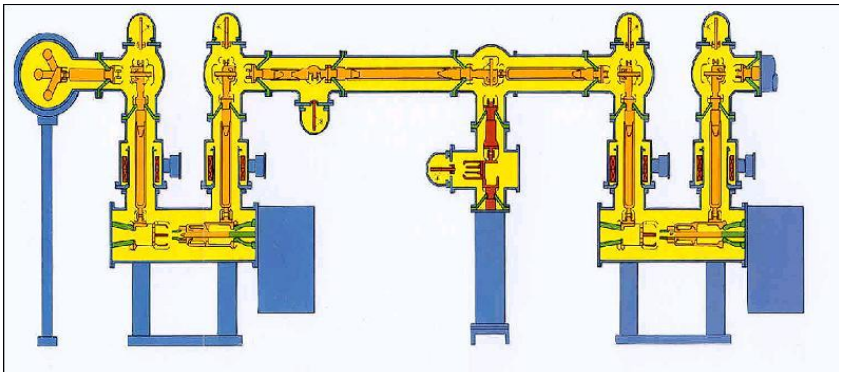
Three phase enclosure GIS (145 kV)





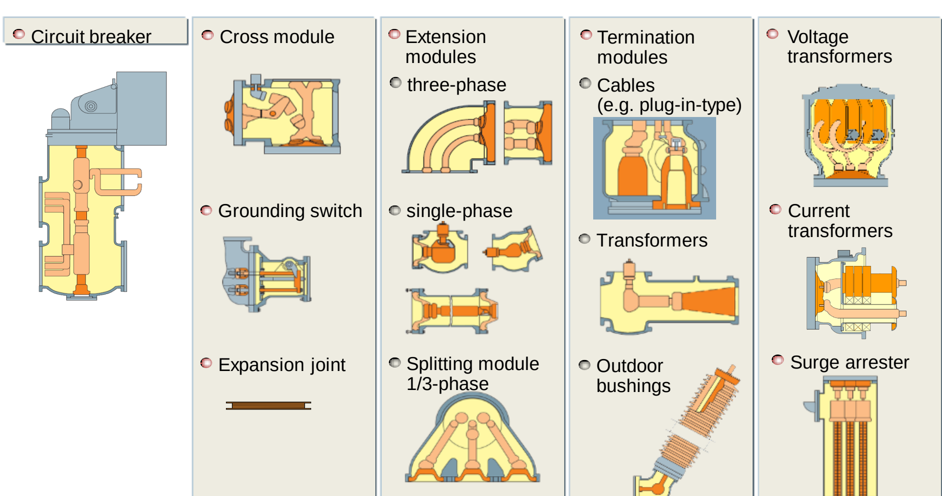
* Module w disconnect & grounding switch

Single phase enclosure (>245 kV)

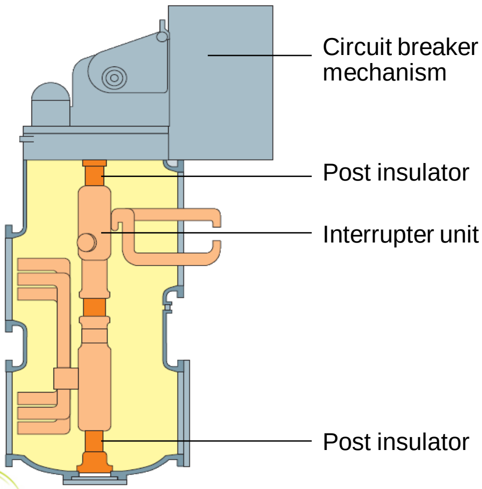


Busbar | Disconnector, Current Transformer, Circuit Breaker | Cable Connection | Disconnector, Current Transformer, Circuit Breaker

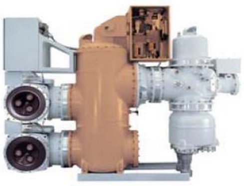
Modular Structure (schematic)



Circuit Breaker Module



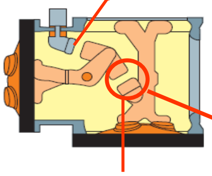
GIS CB



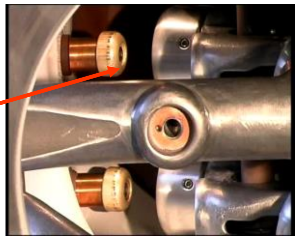
Dead Tank CB

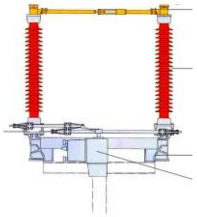
Disconnector/ Ground Switch Module

Grounding Contact



Disconnect Contact





Air insulated disconnector

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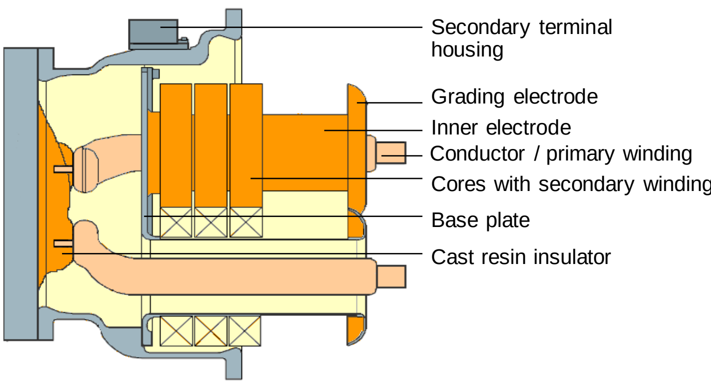
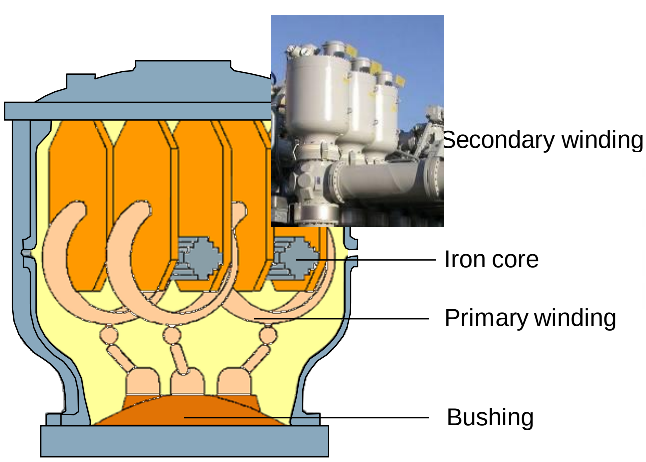
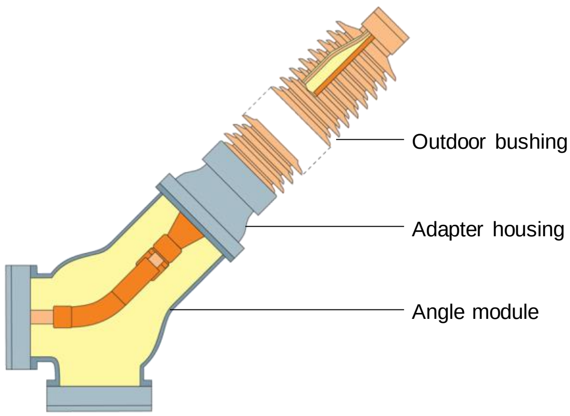
Current Transformer



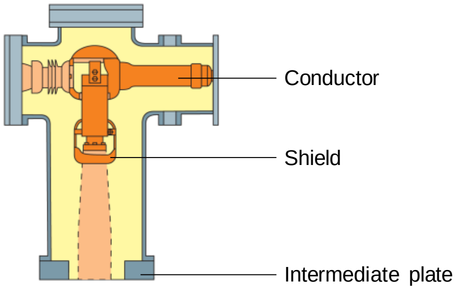
Voltage Transformer

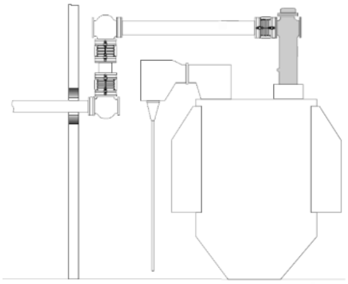


Outdoor Termination

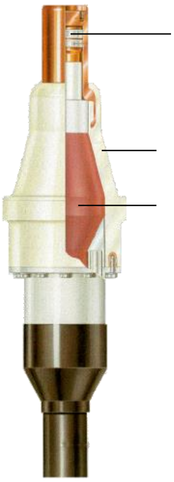


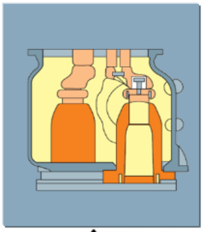
Transformer Termination



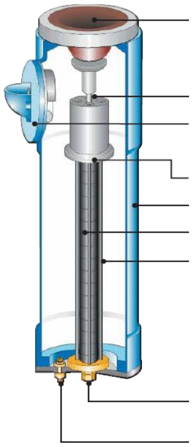


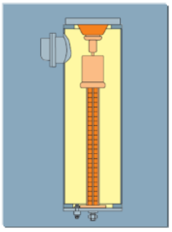
Cable Termination





Surge Arrestor





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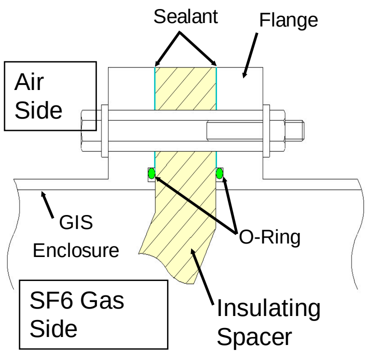
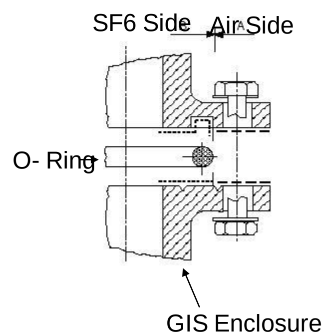
Sealing Systems

O- rings and sealants to provide gas tight systems





The leakage rate from any single gas compartment to the atmosphere shall not exceed 0.5 % per year.*
Practical experiences to the today's design of GIS show leakage rates as low as 0.1 % per year per gas compartment.

* IEEE Std C37.122 – 2010, IEEE Standard for High Voltage Gas- Insulated Substations Rated Above 52 kV

Content

- Testing
- Operations
- Maintenance

Production (Routine) Tests
Pressure, Mechanical, Dielectric, Resistance, Thightness

Testing
High-Voltage AC Testing 1000 kV test stand
Example: GIS Bay 300 kV

PD Measurement

Operations

- Equipment thermal loading
- Reclosing philosophy
- Disconnect and ground switch position (viewports)
- Interlocking
- Remote/local operations (control/marshalling cabinet)
- Alarms

Operations
Disconnect Switch Position Indicator

Operations
Manual Operation and Pad Lock

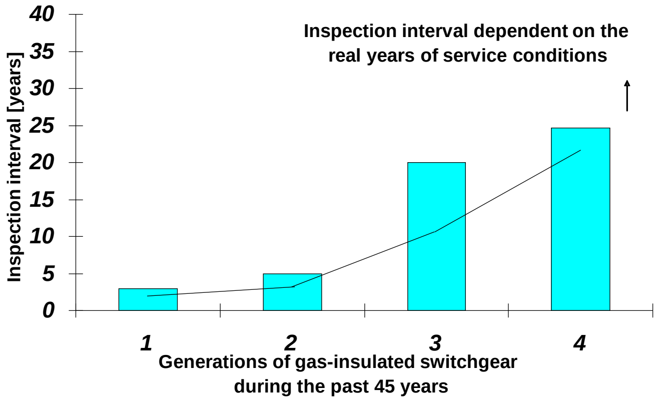
Operations
View Port with Endoscope/Video Camera

Disconnect switch shown in open and closed position through a view port camera

Maintenance/Inspections

- Time Based Intervals
- Load Depended Intervals
- Condition Monitoring Based Intervals

Maintenance
Progress of Maintenance/Inspection Activities



Condition-Based Maintenance

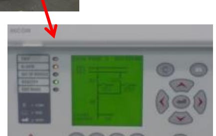
- Routine Inspection
  - External visual inspection of the GIS installation
    - Status of gas density monitors
    - Condition of gas seals and operating mechanisms
    - Integrity of ground and other connections
    - Number of operations

  In intervals of two to five times a month, depending on operating conditions.
- Condition-Based Maintenance
  - Only required after an internal fault or if maximum number of operations has been exceeded.
  - Both are extremely rare!

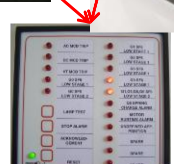
Content
Part 1

- Control
  - Indications
  - Alarms
  - Operating controls
  - Interlocking/ Blocking

Control
Local Control Cubicle (LCC)



Digital bay controller



Hardwire with electromechanical relays

Control - Alarms

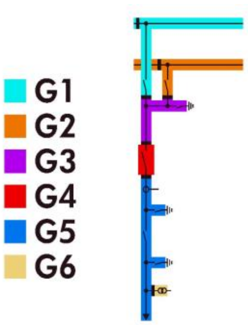
Typical alarms:

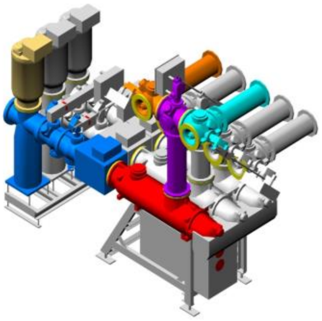
- Supply power CB open
- CB spring charge time exceeded
- CB spring discharged
- CB trip coil failed
- Operating time of switch exceeded
- Switch not in end position(abnormal position alarm)
- Voltage Transformer secondary fuse or CB open
- Gas under/over pressure alarms
- Gas monitoring plug disconnected
- Bay controller status(healthy, out of service, in programming mode, etc.)

Content
Part 1

- Monitoring
  - SF6 Gas Density Monitoring
  - Circuit Breaker Condition Monitoring
  - Partial Discharge (PD) Monitoring
  - Arc Location Monitoring
  - Surge Arrester Monitoring
  - High Voltage Detection System (HVDS)

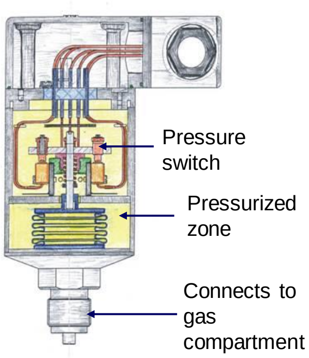
SF6 Gas Density Monitoring

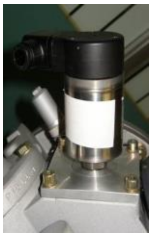


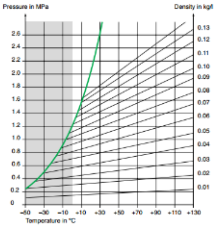


A typical GIS bay's gas zones are shown. Some gas zones are more critical than others; for instance a certain gas pressure/ density is critical for correct operation of the circuit breaker.

SF6 Gas Monitoring – Pressure Monitoring







The simplest way to monitor density is to measure pressure with a simple pressure switch and make a conversion using a chart. Inherent issue with this method is that pressure changes with temperature and for environments where there are large fulgurations in temperature, the measurements can be inaccurate. Pressure monitoring in these cases may also lead to false alarms and incorrect interlocking functions. The newer versions of the pressure monitors have a temperature compensation function eliminate some of these issues.

Content
Part 1

Installation and Commissioning

A Preparation
B Installation steps
C Commissioning and on-site testing

Preparation

Requirements:

EHS instructions

Qualified people

Clean environment

Drawings and diagrams

Tools and materials on-site

Installation steps - aligning the GIS

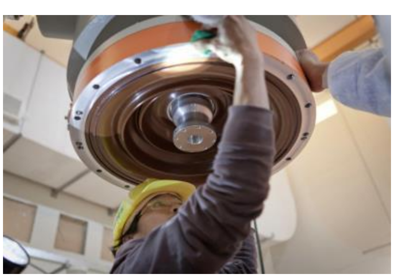
Check for clean floor and that components are damage free

Determine longitudinal and lateral axes

Mark GIS set up points

Assemble GIS bay by bay

Installation steps - flange treatment



Insulators are not damaged

Flanges are scratch free

Cleanliness matters!

Commissioning and on-site testing
High voltage impulse testing

Voltage divider

Impulse generator

Lightning impulse test additional to power frequency test for > 245 kV GIS

Alternative if no partial discharge measurement possible

Detects peaks on conductors and loose particles

Content
Part 2

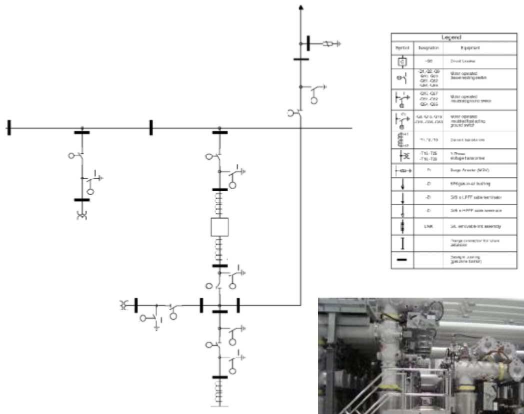
- **Specification**
- **Documentation**

Major Specification Content Areas

- Detailed One-Line Diagram
- General Arrangement of Equipment
- Primary Equipment Data and Ratings
- Gas Zone Configuration
- Secondary Equipment Data
- Engineering Studies
- Logistics Studies
- Test and Inspections
- Standards and Regulations
- Project Deliverables
- Other Project Specific Requirements to Consider

Detailed information and check lists for the specification of GIS can be found in IEEE C37.123 Annex A

Detailed One Line Diagram



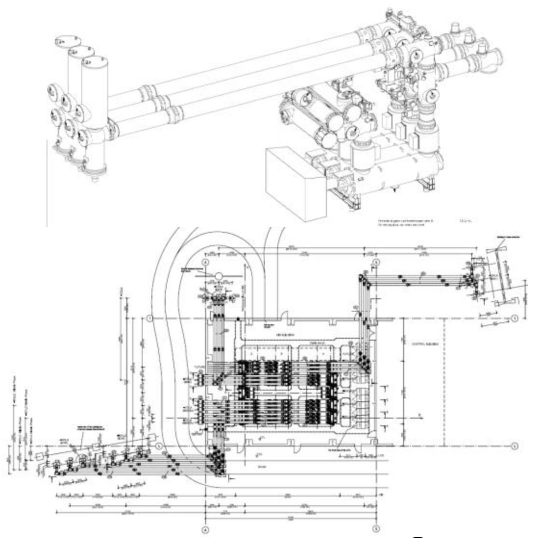
One-line should show the following equipment:

- High Voltage Circuit Breakers
- Current Transformers
- Primary Disconnect Switches with Operator Type
- High Speed Ground Switches with Operator Type
- Grounding Switches with Operator Type
- Voltage Transformers
- Main Buses and Lines
- Terminal Interfaces (i.e. Cable terminations, SF6 Gas-to-Air Bushings etc.)
- Gas Barrier Insulators
- Surge Arresters
- Removable Bus Links

One-line should be drawn in a semi-physical orientation

General Arrangement of Equipment

- Prefabricated, factory assembled, tested, and **shipped in the largest practical assemblies**
- Sufficient space and **access** areas for ready **removal and reinstallation** of each component
- **Optimized arrangements** to reduce installation time, provide ease of operation, minimize maintenance and repair costs, and **facilitate future additions**
- All gauges, viewports, and gas fill points **readily accessible and viewable** by maintenance personnel
- Give **special attention** to the connections between the GIS and other components of the network **overhead lines, transformers, cables** etc. can have **major impact on the overall layout and cost**



Primary Equipment Data and Ratings

Circuit Breakers	
Rated maximum voltage	XXX kV for circuit breakers defined as "definite purpose for fast transient recovery voltage rise times" per ANSI/IEEE C37.06.1; OR XXX kV for "general purpose" per ANSI/IEEE C37.06
Rated maximum interrupting time	X cycles on a 60 Hz basis
Rated minimum current, all breakers	X,XXX A
Rated short-circuit breaking current	XX kA rms
Rated closing and latching current	XXX kA peak
Rated operating sequence	Duty Cycle: O-t1-CO-t2-CO where t1 = 0.3 second, and t2 = 3 minutes
Rated capacitive switching currents	IEC 60056 Table 5
Number of mechanical operations	10,000 (minimum)
Number of trip coils	X
TRV, and time to peak @T100	XXX kV; XXX microseconds
TRV, and time to peak @T60	XXX kV; XXX microseconds
TRV, and time to peak @T30	XXX kV; XXX microseconds
TRV, and time to peak @T10	XXX kV; XXX microseconds
Closing resistor (if required), resistance and insertion time	X ohm; XX microseconds
Disconnect Switches	
Rated minimum current, all disconnect switches	X,XXX A
Rated short-time withstand current	XX kA
Rated peak withstand current	XXX kA
Rated duration of short circuit	1 second
Mechanical endurance	1,000 cycles (minimum)
Grounding Switches	
Rated minimum current, all grounding switches	X,XXX A
Rated short-time withstand current	XX kA
Rated peak withstand current	XXX kA

- General Criteria
- GIS Equipment Ratings and Service Conditions
- Enclosure Design - Single Phase or Three Phase
- Specific Equipment Requirements
- Circuit Breakers
- Disconnect Switches, Grounding Switches and Operators
- Gas System and Gas Zone Configurations
- Current Transformers
- Inductive Voltage Transformers
- Metal-Enclosed Surge Arresters
- SF6 Gas-to-Air Bushings
- GIS to Cable Connections
- GIS to GIB/GIL Connections
- Power Transformer Bushing Connections
- Local Control Cabinets and Marshaling Cabinets
- Ladders, Platforms, Stairs, and Walkways

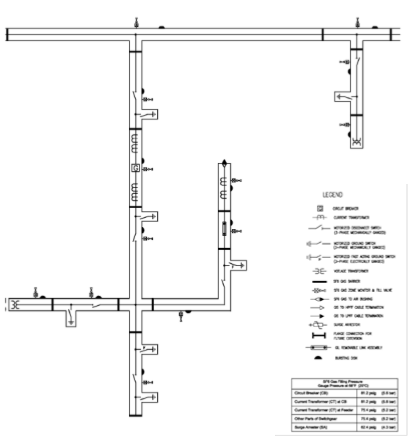
Primary Equipment Data and Ratings

- The manufacturer should provide a **breakdown of the primary equipment specifications** in the preliminary engineering budgetary proposal and the final proposal
- The manufacturer should provide a **full set of ratings** for the primary equipment
- The manufacturer should provide complete fill-in data on all specified components
- The user and manufacturer should **meet to reconcile all user requirements** with the manufacture's proposed design

Disconnect Switch Example

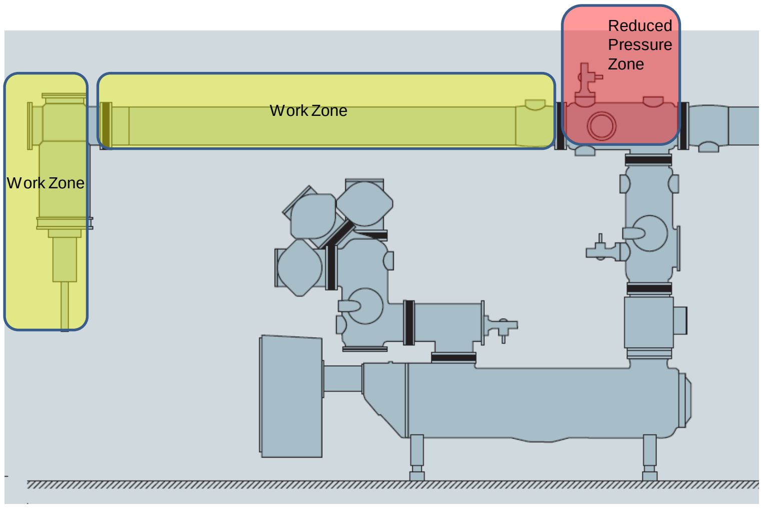
	User Requirements	Supplier Proposal
Rated full-wave impulse withstand voltage		
Across the open gap (kV Peak)		
Power frequency - one (1) minute withstand voltage:		
Across the open gap (kV rms)		
Number of open-close operations before inspection or servicing		
Maximum control voltage (VDC)		
Minimum control voltage (VDC)		
Motor Current, start/run (A)		
Rated peak withstand current (kA rms)		
Short term withstand current (kA rms)		
Maximum opening current (A) at rated voltage		
Maximum closing current (A)		
Heater power per three (3) pole switch (W)		
Main current carrying contact material		
Base material and specification		
Contact insert material		
Plating material		
Control data for operating mechanism		
Operating time (s)		

Gas Zone Configuration



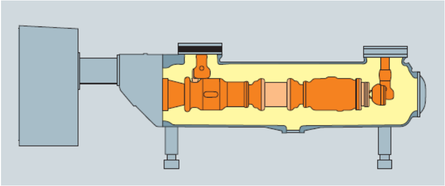
- Ability to **calibrate density monitors** without de-energizing the equipment
- 3-in-1 enclosure = three-phase gas pressure and density monitoring; single-phase enclosure = single-phase gas pressure and density monitoring
- **Leakage rate of SF6 gas** from any individual gas compartment and total leakage from GIS system not to exceed **0.1 percent per year**
- Connections for a gas density relay/monitoring system, gas handling equipment, moisture detection instrumentation and fittings to **permit the addition of SF6 gas while GIS components are in service (energized)**
- Each gas zone with a switching should be furnished with a gas density monitoring device
  - First alarm - Low gas density (nominally 5-10 percent below nominal fill density) to local annunciator and to user's SCADA RTU
  - Second alarm - Trip circuit breakers associated with the affected gas zone before minimum gas density to achieve equipment ratings is reached and block closing of circuit breakers associated with the affected gas zone

Gas Zone Configuration



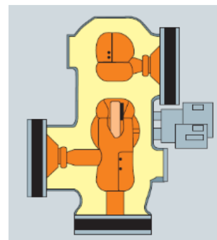
Circuit Breakers

- Designed in the same manner as dead tank SF6 puffer and arc assist circuit breakers that are used in air insulated substations
- **All gauges, counters, and position indicators should be readable by an operator standing near the equipment at floor level**
- Provide for **onboard condition monitoring systems** and transducers to monitor:
  - Timing
  - Travel
  - Mechanism pressure
  - Trip and close currents
  - Auxiliary DC supply voltage
  - AC phase currents and voltages
  - Auxiliary switch positions
  - Circuit breaker bay temperature
  - SF6 gas density and pressure
  - Cumulative I2t calculation
- Mechanism charging motor to be a **universal AC/DC motor**, field selectable



Disconnect Switches, Grounding Switches and Operators

- Disconnect switches and grounding switches, gang and motor-operated, non-load break, with one operating mechanism per three-pole switch
- **Provisions for bypassing electrical interlocking scheme** between the disconnect switch and the grounding switch to **facilitate voltage and current testing of the internal parts of the GIS without removing SF6 gas or opening the enclosure**
- **Viewports accessible from the floor by personnel**
- If not then dedicated optical cameras at each viewport with viewing monitor and cabling system
- Furnish **maintenance platforms, ladders, and/or stairs to access all of the viewports**



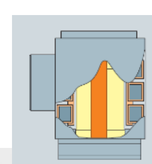
Current/Voltage Transformers

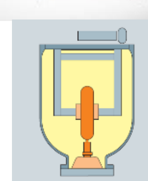
Inductive Current Transformers

- Current transformer secondaries terminated to six-point shorting terminal blocks in the Local Control Cabinets
- Each **current transformer able to be tested without the removal of gas**

Inductive Voltage Transformers

- Inductive voltage transformers to have an **electric field shield between the primary and secondary windings** to prevent capacitive coupling of any transient voltages
- Voltage transformers **fabricated to mitigate the possibility of ferroresonance** during operation, with provisions for damping equipment

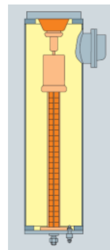




Metal Enclosed Surge Arrester / Bushings

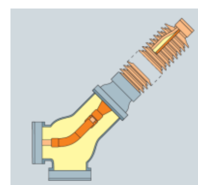
SF6 Gas to Air Bushings

- Provide surge arresters to protect underground cables connected to the GIS from impulse surges
- **Arresters connected to the SF6 cable sealing end at the junction of the cable connection**
- Insulation coordination studies to ensure proper surge arrester application



SF6 Gas to Air Bushings

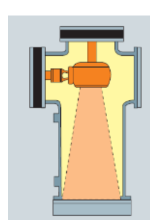
- Internal **metal shields** installed in the bushing cylinder **to control electric field distribution**
- Each gas-to-air bushing to have its own **gas zone and gas density monitoring transducers**, transducers **accessible from the ground using a step ladder or improvised platform**



Cable Sealing End Terminations / Transformer Terminations

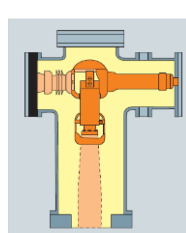
Cable Sealing End Terminations

- Removable link or plug in connector that allows current transfer from the cable conductor to the GIS conductor, so that it can be disconnected from the GIS when testing is performed on either the GIS or the cable
- **MOV arresters across cable to sealing end interface**



Transformer Terminations

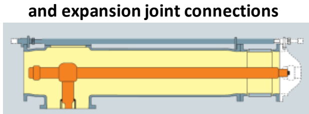
- **Appropriate grounding connections across the flanges** of the transformer termination module
- **Expansion joints** to compensate for the following:
  - design tolerances of the facility, the building and the transformer
  - one-off movements caused by differences in the settling of the transformer and facility foundations
  - thermal expansion of component enclosures.

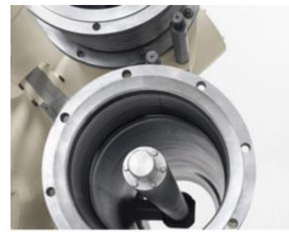


Gas Insulated Bus / Walkways, Ladders and Platforms

Gas Insulated Bus

- Expansion joints between individual bays
- **Proper grounding across flange and expansion joint connections**





Walkways, Ladders and Platforms

- **Provide detailed drawings for platforms, stairs, walkways and ladders for safe, efficient access to all viewports, actuator mechanisms, switch operators, gas density monitoring equipment, etc., for maintenance and operations personnel**

Local Control (LCC) (Marshalling) Cabinets and Secondary Equipment

- **One local LCC for each circuit breaker bay**
- Marshaling cabinets may also be required as intermediate termination locations between the GIS and LCC and LCC and the substation control room
- **Rear access door all external cabling terminated in the rear of the cabinet**
- Protection/Control and Monitoring Requirements
- Logic Diagrams for Numerical Relays
- SCADA Interface Points
- Wiring Connections and Interconnections Requirements
- Annunciation and Alarms
- AC Station Service
- Mimic Bus Diagram

Content
Part 2

Interfaces

•GIS – Air

•GIS – Cable

•GIS – Transformer

•GIS – GIS

GIS Interfaces

- GIS Interfaces are used to connect the GIS to other components in the substation and the connecting network. The following interfaces are available:
  - GIS to air by bushings
  - GIS to cable
  - GIS to transformer
  - Connecting new GIS to existing GIS

Standards concerning GIS Interfaces

IEEE C37.017	GIS Bushing to air
IEC 62271-209	Direct connection of GIS to fluid filled or dry type cables
IEC 62271-211	Direct connection of GIS to transformers
IEEE C37.122.6	Interface of existing GIS to new GIS
CIGRE TB 605	Recommendations for plug-in, dry type cable connection to GIS

GIS to air bushing interfaces

3-phase interface

1-phase interface

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SF6 to air bushing

… or on supporting frame and GIB trunking

GIS to cable interfaces

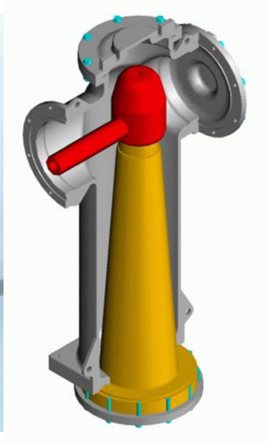
3-phase interface

1-phase interface

GIS cable connection

Conus of the cable end

GIS enclosure of cable interface



Cable interface principle

GIS to transformer interfaces

3-phase interface

1-phase interface

GIS transformer connection
SF6 to oil bushing interface

GIS to GIS interfaces

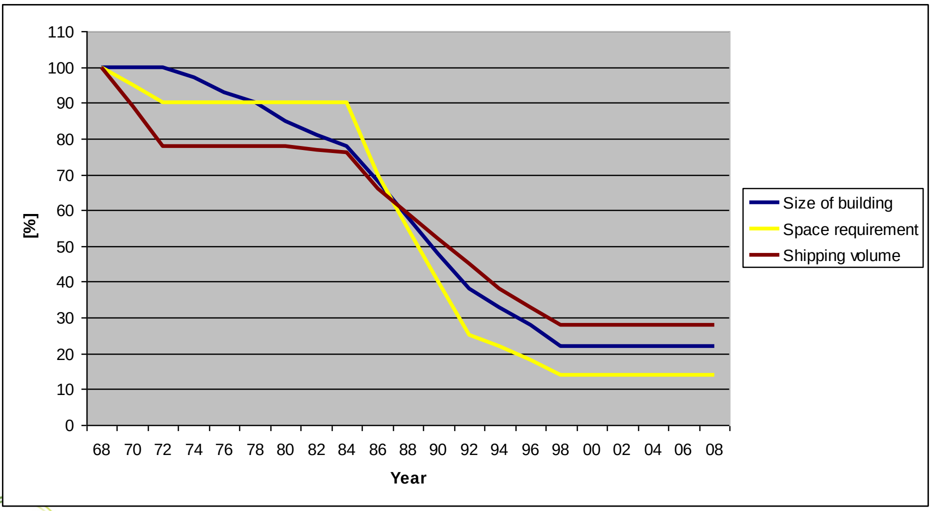
Between same manufacturer

Between different manufacturers

Content
Part 2

GIS Evolution & Future Development
- GIS – Futher Seize Reduction
- GIS – Low Power Instrument Transformers
- GIS – Alternative Insulating Gases

GIS Size Reduction
Progress of GIS Development (145 kV)



GIS size reduction over a 47 year period

Amount of SF_6 has been reduced by about 70%

47 years in service
GIS 123 kV, 31.5 kA

State of the art
GIS 145 kV, 40 kA

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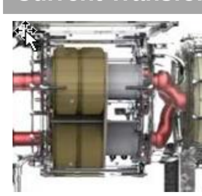
Conventional and Low-Power Instrument Transformers for High Voltage GIS

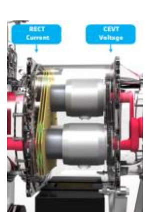
Conventional Technology

Conv. inductive CT
Current Transformer

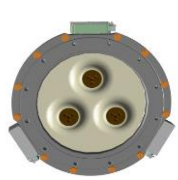


Conv. inductive VT
Voltage Transformer

Low-Power Instrument Transformer (LPIT) Technology



LPIT



GIS integrated sensors

Rogowski Coil
(current measurement)

Electric Field Probe, **Capacitive Electric Voltage sensor**
(voltage measurement)

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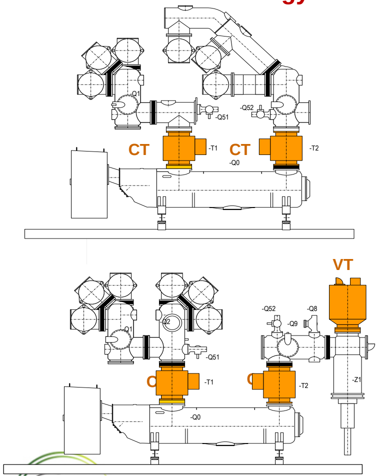
Low-Power Instrument Transformer (LPIT) Technology reduces dimensions and weight of the GIS

Conventional (inductive) Measurement Technology



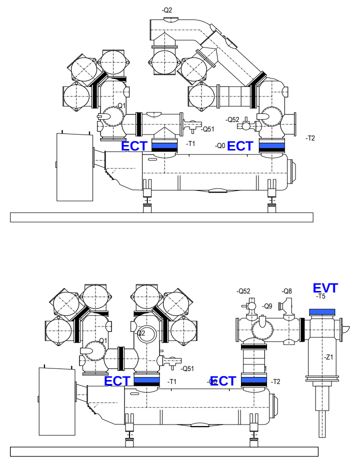
Reduces:

~ 90% of instrument transformer weight

~ 15% of GIS height

SF_6 amount

Low-Power Measurement Technology



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Alternative gases to SF_6 Status today

SF_6 has excellent electrical characteristics
→ Potent greenhouse gas with a high GWP

There are no restrictions so far on the application of SF_6 in HV
→ Included on the list of the fluorinated substances in the Kyoto protocol and the EU-F-Gas-regulation 517/2014

Responsible gas-handling only with state-of-the-art equipment
→ Less preventive actions of gas handling preferable

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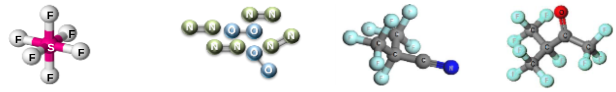
Characteristics of different gases for GIS



		Sulfur-hexafluoride	Clean-Air	Fluoronitrile	C5-Fluoroketone
Pure Gas	Chem. formula	SF_6	$N_2 + O_2$ (80% / 20%)	$(CF_3)_2CFCN$	$(CF_3)_2CFC(O)CF_3$
	CO_2-equivalent (GWP)	22.800	0	2.210	1
	Boiling point	-64°C	< -183°C	-5°C	+27°C
	Dielectrical strength	1*	0.43	2.2	1.7
Gas mixture	Background gas(es)	pure or in combination with N_2, CF_4	$N_2 + O_2$ (80% / 20%)	~ 90% CO_2	~ 90% O_2 with N_2 or CO_2
	CO_2-equivalent (GWP)	< 22.800	0	~ 380	<1
	Lowest operation temp.	- 30°C	- 30°C	~ - 25°C	0°C to +5°C
Reaction during internal arc	Decomposition products	Hydrogen fluoride, sulfur dioxide, sulfur compounds	If applicable: Ozone and nitric oxide	Amongst others: carbon monoxide, carbon dioxide, hydrogen fluoride	
	Toxicity of decomposition products	Hazardous when inhaled, causes skin, and eye irritation[1]	No decomposition products	Hazardous when inhaled, causes skin and eye irritation	

[1] All Safety measures are defined and implemented
* Relative dielectric strength, standardization on SF_6

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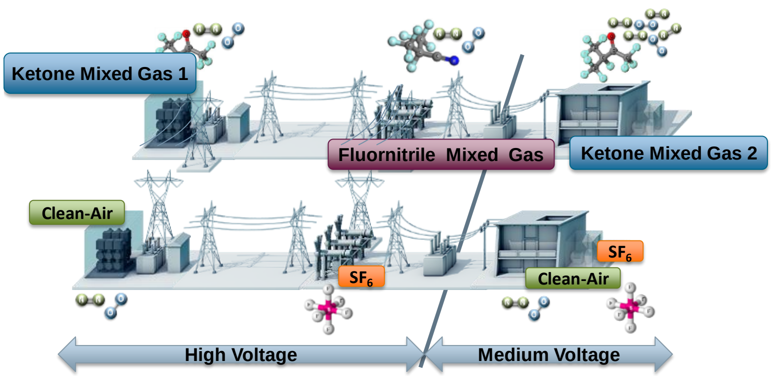
Different gases - different gas handling procedures



From

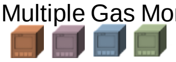
GIS Service Car

One Gas Monitoring

to

GIS Service Fleet

Multiple Gas Monitorin



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Further steps to establish alternatives to SF_6

Users and manufactures need to be aligned on a SF_6 alternative solution considering also gas handling procedures

Further elaborations on technical parameters within working groups such as

NEMA	CIGRÉ	T&D Europe	IEC
Electric T&D SF_6 Coalition	WG D1.51	Gases for Switchgear	TC17 AHG 5

Experiences with pilot projects to be evaluated

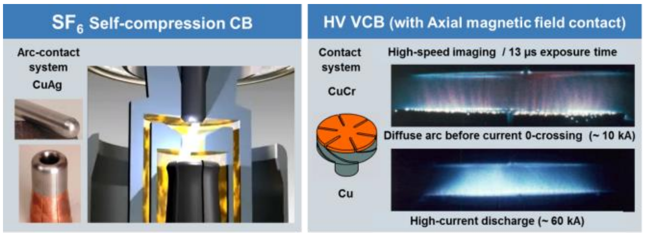
Content
Part 2

GIS Next Step

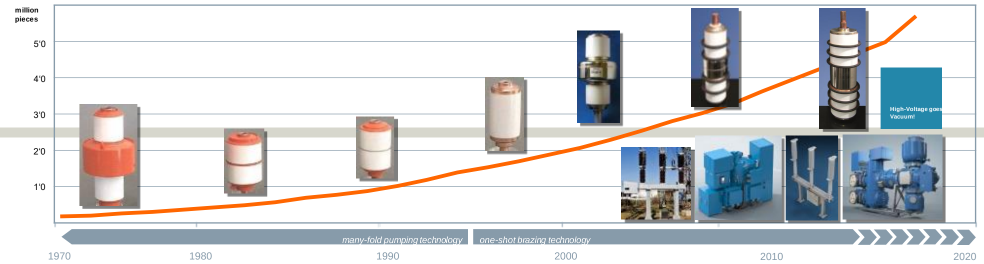
- **GIS – Clean Air Insulated**
- **GIS – Vaccuum Switch Technology**

SF_6 Alternatives – Key Advantages Vacuum Switching

- ✓ Short circuit breaking performance equivalent to SF_6
- ✓ High mechanical (M2) endurance (less drive energy required)
- ✓ Enhanced electrical endurance because of lower contact wear
  -> arc voltage & arcing times of Vaccuum Circuit Breaker (VCB) are significantly lower
  -> number of possible VCB switching operations is significantly higher



Vacuum interrupter – Development of product / production technology



1971
First serial manufacturing of vacuum interrupters for contactors.

- More than 40 years of operational experience in the field of medium voltage applications
- More than 5.5 million vacuum interrupters delivered only from Siemens

2010
Introduction of prototypes for 72.5 kV

2016
Introduction of 145 kV portfolio with vacuum interrupter for up to 72.5 kV and up to 145 kV

Vacuum interrupter technology – Operational and environmental value

For more than 40 years successful operational experience in medium-voltage, since 2010 in high-voltage

- **High reliability**
  due to the hermetically tight vacuum interrupter,
  eliminating any influence of decomposition products
- **High performance**
  Perfect for frequent switching applications: Excellent interrupting performance at rated nominal current and rated short-circuit currents throughout life-time of the vacuum circuit-breaker, up to 30 short-circuit interruptions
- **Perfect for low temperature**
  No liquefaction of switching medium
- **No maintenance**
  Maintenance free due to sealed for life technology; no spare part costs
- **No CO_2e emissions**
  Switching media (vacuum) with GWP=0;
  no CO_2e emissions during operation, maintenance or recycling

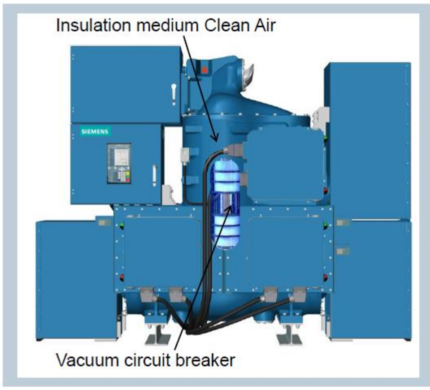
CO2 NEUTRAL

GIS up to 72.5 kV / 25 kA

Technical data

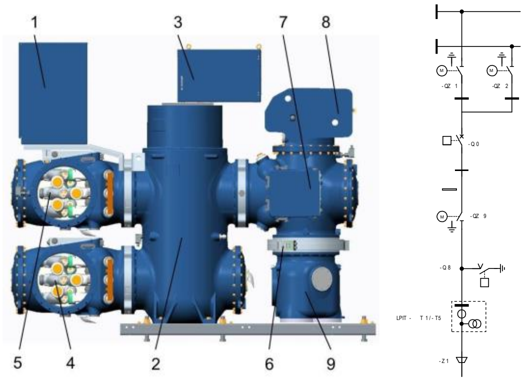
Switchgear type	8VM1	
Rated voltage	up to	72.5 kV
Rated frequency		50 Hz
Rated short-duration power-frequency withstand voltage (1 min)	up to	140 kV
Rated lightning impulse withstand voltage (1.2 / 50 µs)	up to	325 kV
Rated normal current	up to	1250 A
Rated short-circuit breaking current	up to	25 kA
Rated peak withstand current	up to	68 kA
Rated short-time withstand current (up to 1 s)	up to	25 kA
Leakage rate per year and gas compartment (type-tested)		< 0.1 %
Driving mechanism of circuit-breaker		stored-energy spring
Rated operating sequence		O-0.3 s-CO-3 min-CO CO-15 s-CO
Interrupter technology		Vacuum
Insulation medium		Clean air
Weight of SF_6 or other flourinated greenhouse gases		0 kg
GWP Global Warming Potential		0
CO_2 equivalent		0 kg
Rated filling pressure		0,56 MPa abs
Bay width common pole drive		1050 mm
Bay hight, depth (depending on bay arrangement)		2330 mm x 2500 mm
Bay weight (depending on bay arrangement)		1,6 t
Ambient temperature range		-30 °C up to +45 °C
Installation		indoor
First major inspection		> 25 years
Expected lifetime		> 50 years
Standards		IEC

Other values on request



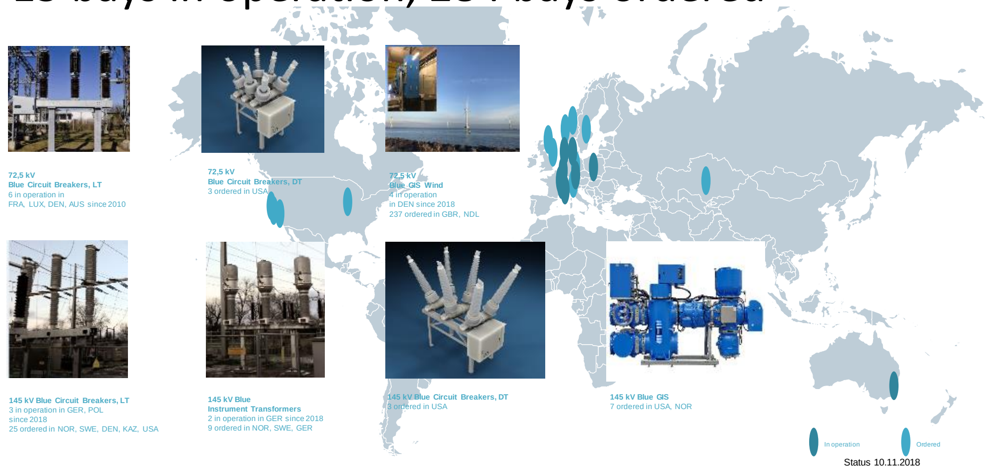
Blue GIS 145 kV /-
Example with Low-Power Instrument Transformer

1 Integrated local control cubicle
2 Circuit-breaker with vacuum interrupter
3 Spring-stored-energy operating mechanism with circuit-breaker control unit (common drive)
4 Busbar I with disconnector and earthing switch
5 Busbar II with disconnector and earthing switch
6 Low-Power Instrument Transformers (LPIT)
7 Outgoing module with disconnector and earthing switch
8 Make-proof earthing switch (high speed)
9 Cable sealing end



The design is modular using SF6 platform components ensuring all substation grid configurations. The gas pressure amount to 6.9 bar, which is only slightly higher than that of SF6 145 kV GIS.

References Blue Products
15 bays in operation, 284 bays ordered



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Next steps of
Blue Products and Vacuum Switching Technology

- ✓ Vacuum switching technology up to 420/550 kV, nominal currents 4000 A, short circuit currents 63 kA for 50/60 Hz in foreseeable future:
- ✓ First successful high-power & dielectric tests on single-break prototype VI for next SF6-free products for 245 kV & higher as series connection of VIs

VI 170 kV / 50 kA and 245 kV / 63 kA

170 kV VCB: Diffuse AMF vacuum arc at 20 kA peak

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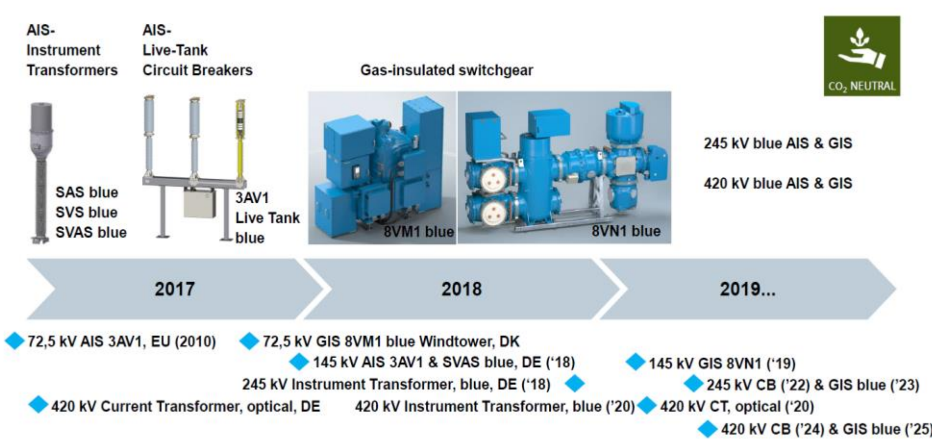
Next steps - Blue Products Roadmap



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Content
Part 2

Gas Insulated transmission Lines (GIL)

Introduction to GIL

Length 17 km – PP9 Saudia Arabia
Longest 420 kV GIL installed in the world

System Length 1 km - Palexpo, Switzerland
Underground Part of a GIL/Overhead Line

Xiluodu, Sichuan, China

Jinping, China

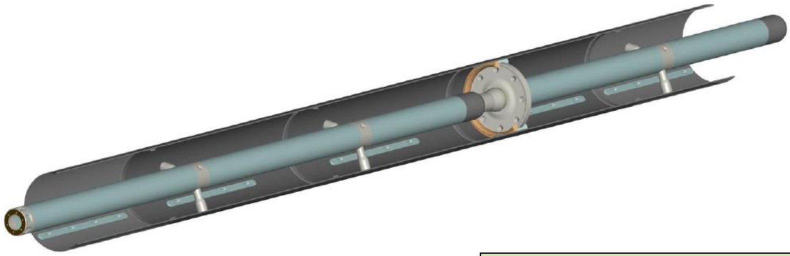
Technical Data GIL

Rated voltage	245 kV … 550 kV
Impulse voltage	… 1.675 kV
Rated current	2.000 … 5.000 A
Rated short time current	62 kA / 3 s
Rated Power	up to 4.700 MVA
Capacitance per length	55 nF/km
Overload capability	100 %
Insulating gas	0-80 % N_2 / 100-20 % SF_6

IEC 62271-204 High-voltage switchgear and controlgear –
Part 204: Rigid gas-insulated transmission lines for rated voltage above 52 kV

IEEE C37.122.4 Application and User Guide for Gas-insulated Transmission Lines (GIL), Rated 72.5 kV and Above

GIL Principle Structure

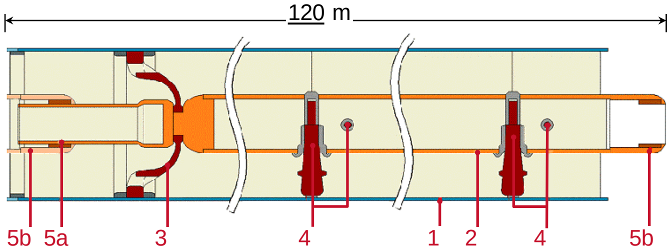


- Standardized Modules
- Flexible Technical Solutions
- Fast Assembly and Laying

Straight Unit

- Typical length of 120 m
- Bending radius down to 400 m

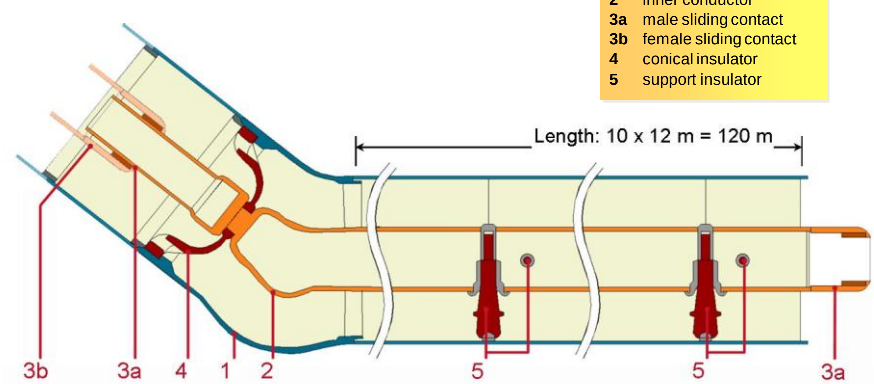
1 enclosure
2 inner conductor
3 conical insulator
4 support insulator
5a male sliding contact
5b female sliding contact



Angle Unit

- For directional changes
- Flexible angle from 4° to 90°

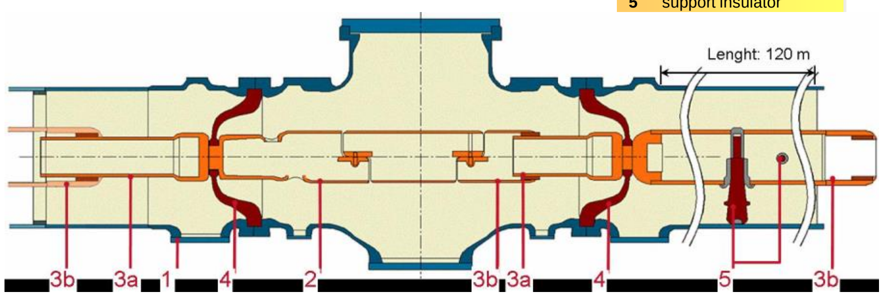
1 enclosure
2 inner conductor
3a male sliding contact
3b female sliding contact
4 conical insulator
5 support insulator



Disconnector Unit

- Separation of gas compartments
- Connection point for sectional commissioning of the GIL
- Location of the decentralized monitoring units

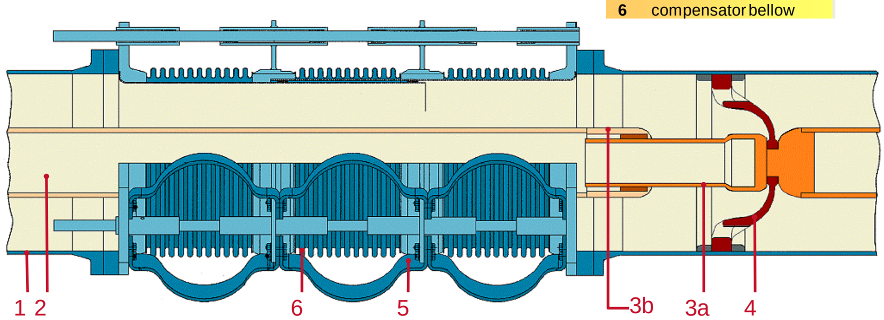
1	enclosure
2	inner conductor
3a	male sliding contact
3b	female sliding contact
4	conical insulator
5	support insulator



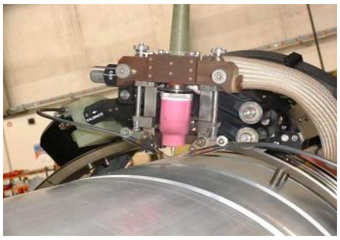
Compensation Unit

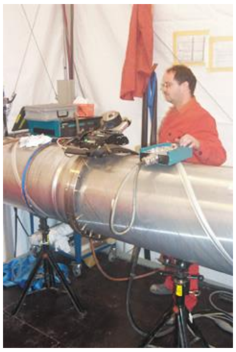
- Compensation for the thermal expansion of the enclosure
- Flexible connectors are leading the current

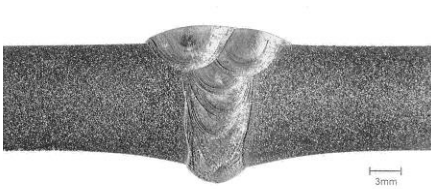
1	enclosure
2	inner conductor
3a	male sliding contact
3b	female sliding contact
4	conical insulator
5	flexible connector
6	compensator bellow



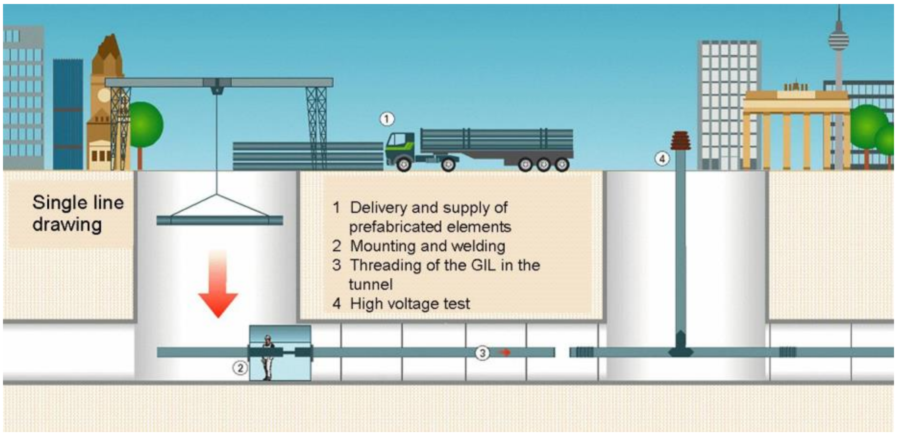
High Quality Automated Arc Welding





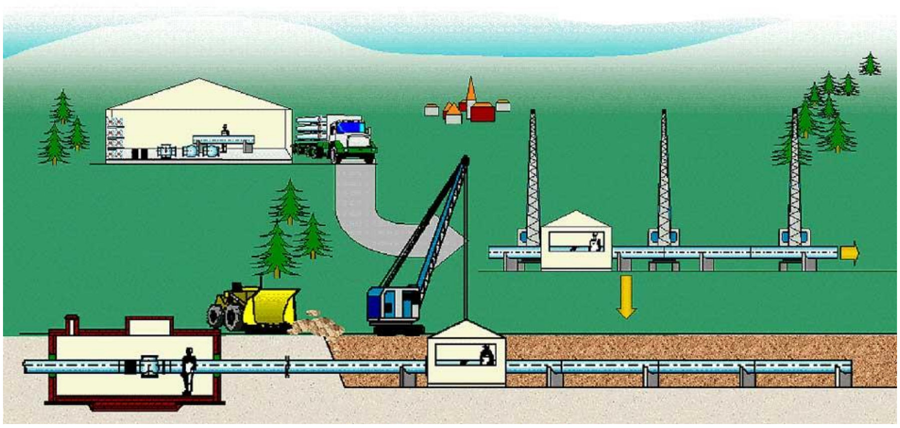


Tunnel Laying Process



IEEE/PES Substation Committee- GIS Subcommittee

Directly Buried Laying Process



Shipping and Transportation

Delivery
Transport Units

Installation and Commissioning

Shaft Welding Tent in the Tunnel

Application of GIL in a Cavern

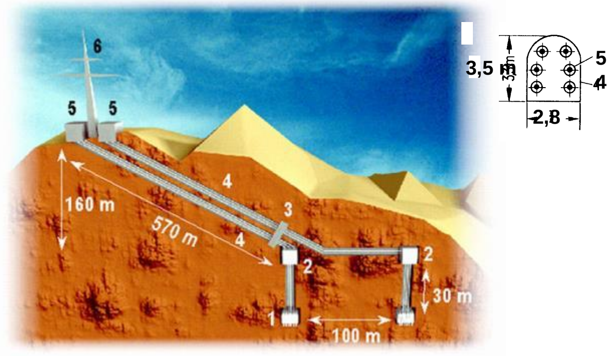
- **Schluchsee, Germany**
- Ratings

U_r	420 kV
I_r	2500 A
U_{BIL}	1640 kV
I_s	53 kA

- Single line, physical arrangement
  GIL laid in a tunnel through a mountain
  Connection of cavern power plant to the overhead line

Applications of GIL in a Cavern

1. 600 MVA Transformer
2. Encapsulated Surge Arrestors
3. Transfer Switching units
4. GIL Connection
5. Open Air Surge Arrestor
6. Overheadline



Application of N_2/SF_6 Gasmixture GIL in a Tunnel

PALEXPO, Swiss

Commisioned: 2001

The GIL is laid in a tunnel of 500m lenght using 700 m bending radius. It is part of overhead line at the airport of Geneva.

U_r	300 kV
I_r	2000 A
U_{BIL}	850 kV
I_s	50 ka

Applications of Direct Buried GIL

Joshua Falls
installed in 1978
Length 1640m

U_r	145 kV
I_r	2000 A
U_{BIL}	650 kV
I_s	63 kA/3 s

To minimize the overall visual impact of a new station, GIS was chosen for the switchgear and two GIL line exits were direct buried to overhead line access points away from the main GIS equipment.

Application of GIL Above Ground

PP9 1200 MW Combined Cycle Plant in Saudi Arabia, near Riyadh

total length of about 17 km

U_r	420 kV
I_r	1200 A at 55 °C
U_{BIL}	1425 kV
U_{PF}	630 kV
I_s	63 kA

Applications of GIL in Hydropower Station

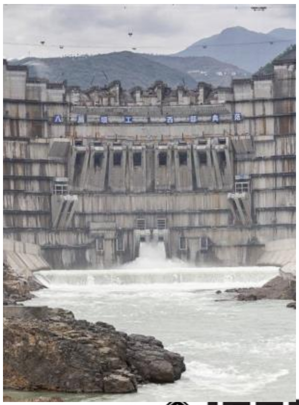
Huanghe Laxiwa

U_r	800 kV
I_r	4000 A
U_{BIL}	2100 kV
U_{SIL}	1550 kV
I_s	63 kA

Application of GIL in a Hydro Dam

Xiluodu GIL
In operation since 2013

Rated Voltage	550 kV	Rated Current	4500 A
Rated Impulse-withstand Voltage	1675 kV	Rated Short-Time-withstand Current	63 kA, 3 s
Single phase length	app. 12.750m;	480m vertical shaft in each circuit	



Application of GIL in a double Tunnel

Langwied, Munich

In operation since 2013

U_r	420 kV
I_r	3150 A
U_{BIL}	1425 kV
U_r	420 kV

View into the tunnel from the connection shaft the overhead line.

View into the tunnel with 400 m bending radius of GIL.

Transition section GIL to overhead line.

Application of GIL Direct Burid with Gasmixture

420 kV Kelsterbach Transmission Line

Customer:	*Amprion GmbH* amprion
Location:	*Airport Frankfurt am Main*
Type:	Buried Installation
Single phase length:	5.400 m
Date of operation:	2011
max. Power Rating:	2 x 2000 MVA
Operational power:	2 x 1800 MVA
Rated voltage:	420 kV
Rated current:	2750 A
Short time current:	63 kA, 1s
Rated impulse withstand voltage:	1425 kV
Key buying factor:	Buried installation technology, small trench width, transmission capacity
Challenges:	World's first buried GIL using N2/SF6 and on-site assembly process

Hermann Koch
IEEE Fellow

Dr. Koch's first professional association was with research on particle discharge measurement methods for non-destructive testing at Technical University Darmstadt, Germany which he concluded with his Ph.D. degree in 1990. In 1991 he joined Siemens Germany, as high voltage switchgear engineer for gas-insulated substations (GIS). In 1994 he became the responsibility to design and develop the gas-insulated transmission technology (GIL) at Siemens. In 2001 he was responsible for the installation of the world wide first GIL with N_2/SF_6 gas-mixture at PALEXPO in Geneva, Swiss. Since 2001 Dr. Koch has managed several GIL project installations worldwide and is now engaged in developing the next step of this transmission technology for DC voltages. In 2010 Dr. Koch received his IEEE Fellow in this technical field.

Dr. Koch is active in international standardization since 1992 in IEC as SC 17C Secretary , in IEEE various chairmen in K0 GIS Subcommittee, Substations chairman and member of the IEEE-SA Board, in CIGRE member of B3 Substations and in Germany DKE related national committees.

Dr. Koch has contributed with more than 30 patents and over 130 publications in the technical field of gas-insulated technology. He has published IEEE books on GIL, GIS and soon on International Standardization published by www.wiely.com

Dr. Koch’s research has opened new technical solutions for the applications worldwide of long distance bulk power underground transmission.

Attendees on the tutorial until today

Conference	Location	Year	Attend
Substations Committee Meeting	Sun Valley, USA	April 2003	20
T&D Conference and Exhibition	Dallas, USA	Sept. 2003	50
Substations Committee Meeting	New Orleans, USA	April 2004	20
PES General Meeting	Denver, USA	July 2004	10
Switchgear Committee Meeting	Tucson, USA	Sept. 2004	40
Substations Committee Meeting	Tampa, uSA	April 2005	20
PES General Meeting	San Francisco (Panel), USA	June 2005	30
IEEE Distinguished Lecturer Program	Dehli, Kolkata, Cheney, India	August 2005	50
Substations Committee Meeting	Scottsdale, USA	April 2006	15
PES General Meeting	Montreal, Canada (Panel), USA	June 2006	20
Substations Committee Meeting	Bellevue, USA	April 2007	15
PES General Meeting	Tampa (Panel), USA	June 2007	15
Substations Committee Meeting	San Francisco, USA	April 2008	20
T&D Conference and Exhibition	Chicago (Panel), USA	April 2008	100
PES General Meeting	Pittsburgh (Panel), USA	July 2008	20
IEEE DLP	Lima, Peru and La Paz, Bolivia	August 2008	50
IEEE DLP	Pune, Kolkata and Kanpur, India	Sept. 2008	70
Substations Committee Meeting	Kansas City, USA	May 2009	15
PES General Meeting	Calgary, Canada	July 2009	10
UHV Test Base State Grid	Beijing, China	March 2010	40
T&D Conference and Exhibition	New Orleans, USA	April 2010	30
PES General Meeting	Detroit, USA	July 2011	10
T&D Conference and Exhibition	Chicago, USA	July 2012	50
ISGT Conference	Berlin, Germany	August 2012	15
IEEE PES ICPEN	Arunachal Pradesh, India	December 2012	45
IEEE PES Austrian Chapter	Graz, Austria	March 2013	45
IEEE PES Costa Rica Chapter	San Jose, Costa Rica	June 2013	55
IEEE PES El Salvador Chapter	San Salvador, El Salvador	June 2013	65
IEEE PES GM	Vancouver, Canada	July 2013	10
IEEE PES CATON	Kolkata, India	December 2013	75
T&D Conference and Exhibition	Chicago	April 2014	65
		Total	1095

Attendees on the tutorial until today

Conference	Location	Year	Attend
Takeover			1095
T&D Conference and Exhibition	Dallas, Tx, USA	April, 2016	50
		Total	1145

Thank you for your attention!

Thank you for your attention, are there any questions?

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