1

Introduction

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1.1 General

This book is based on the tutorial and panel sessions presented by the experts of gas insulated substations in the working group K2 of the IEEE Substations Committee. Gas insulated substations (GIS) were invented in the early 1960s with the first projects in the mid 1960s in the United States and Europe. In thousands of installed bays of GIS today, we can look back to a wide range of experiences gained in very different cases of applications.

The IEEE Substations Committee created GIS Subcommittee K0 more than twenty years ago and since then this subcommittee has continuously worked on standards and guides in the field of GIS technology and application. About twenty standards and guides related to the GIS have been published to-date, with continuous revision work in progress on all documents.

Around the year 2000 the experts of the GIS Subcommittee started to collect information on GIS and developed a tutorial on Gas Insulated Substations (GIS) and Transmission Lines (GIL). This working group is numbered as K2 in the GIS Subcommittee.

1.1.1 Organization

The organization of the Substations Committee has developed over the last decades with the focus on any equipment and systems related to substations. In Figure 1.1 the principal organization of the Substations Committee of today is shown.

In blue, the administrative level shows the chairman as the leader and the legislative administrative subcommittee B0, where all chairmen of the subcommittees of the Substations Committee are voting members. All decisions in the Substations Committee are taken here.

The green boxes are supporters of the chairman to help him carry out all the work by splitting tasks to the vice chairman, secretary, past chairman, standards coordinator, transaction editor,

Gas Insulated Substations, First Edition. Edited by Hermann Koch.

Companion Website: www.wiley.com/go/koch/substations

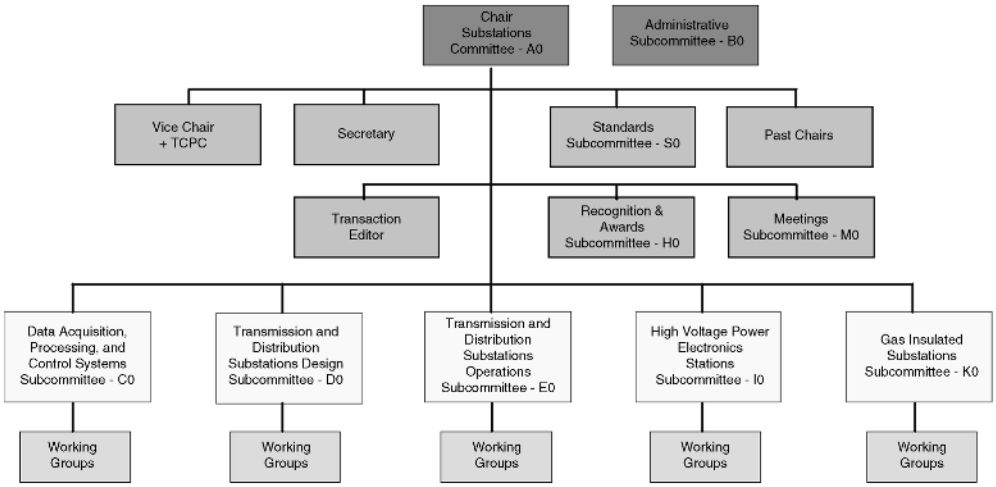

Figure 1.1 Organization of the Substations Committee (Reproduced by permission of IEEE)

awards nominator, and meeting planner. These functions are elected every two years but can be extended by re-elections.

The actual standards' work is done in the working groups organized by the subcommittees, which cover:

C0: Data acquisition, processing and control systems with a focus on substation requirements as part of the overall network

D0: Transmission and distribution substation design for a medium voltage substation in the range of 1 kV up to and including 52 kV and a high voltage substation above 52 kV

E0: Transmission and distribution of substation operations for medium voltage substations in the range of 1 kV up to and including 52 kV and high voltage substations for above 52 kV

I0: High voltage power electronics stations for DC equipment above 1.5 kV to be installed in a substation or converter station like AC/DC converters, coils, filters, grounding, and software for control and protection

K0: Gas insulated substations for AC high voltage equipment above 1 kV of switchgear, disconnectors, and ground switches (GIS) and power transmission (GIL)

The responsibility for the GIS/GIL tutorial is with working group K2. In this working group the content of the tutorial has been worked out and discussed before the tutorials have been presented. Working group K2 has presented the content of the tutorial at IEEE meetings several times, sometimes as a half or full day tutorial or in other cases as a panel discussion, always with the focus to bring the information to the engineers participating from the electric power industry.

In the present case, the tutorial content will be revised and finally published as a GIS Handbook.

Table 1.1 Active members of the tutorial in 2012

Name	Affiliation	Country	Time
Arun Arora	Consultant	US	Since 2002
George Becker	United Illuminating	US	Since 2002
Phil Bolin	Mitsubishi	US	Since 2002
Arnaud Ficheux	AREVA	FR	Since 2008
John Brunke	POWER Engineers	US	Since 2005
Mark Etter	ABB	US	Since 2002
Pat Fitzgerald	CGIT	US	Since 2006
Hermann Koch	Siemens	DE	Since 2002
Venkatesh Minisandram	National Grid	US	Since 2002
Ryan Stone	Mitsubishi	US	Since 2006
Peter Grossmann	Siemens	DE	Since 2008
Charles L Hand	SCE	US	Since 2010
Richard Jones	Tech S Corp/Energy Initiatives Group	US	Since 2003

1.1.2 Experts over the Years

Over the years, a wide range of experts have left their footprint in the tutorial and enriched it with a wide range of information. The members of the tutorial working group K2 have, over the last decade, all contributed with their experiences and knowledge accumulated over many years in many executed projects as users of GIS, manufacturers, or consultants. The working group includes members from the United States of America (US), France (FR), and Germany (DE) to give an international outlook.

The active members are listed in Table 1.1 and the past members are listed in Table 1.2.

1.1.3 Content of the Tutorial

The tutorial is split into modules that cover many aspects of GIS in practical application. The focus of the content is to bring practical knowledge to the engineer to support his or her daily work.

- M1 – Overview. Gives an overview of the content and organization of the tutorial.
- M2 – GIS Basics. Here the basic knowledge of GIS is explained for practical applications.
- M3 – GIS Applications. Here a wide area of applications is given to show the large variations.
- M4 – GIL Basics. Here the basic knowledge of GIL for practical applications is given.

Table 1.2 Past active members

Name	Affiliation	Country	Time
Lutz Boettger	ABB	US	2002 to 2006
Hugues Bosia	AREVA	FR	2002 to 2007
Wolfgang Degen	Consultant	DE	2002 to 2008
Mel Hopkins	CGIT	US	2002 to 2005
Deborah Ottinger	EPA	US	2002 to 2005
Joseph Pannunzio	AREVA	FR	2010 to 2013

- M5 – GIL Applications. Here many applications in typical surroundings and laying methods are explained.
- M6 – Mixed Technology Switchgear. Here the compact or hybrid types of partly gas insulated and air insulated technology is given.
- M7 – SF_6. Here the knowledge of handling, atmospheric impact, and recycling is given.
- M8 – GIS Overloading. Here the specific conditions and rules for overloading of GIS are explained.
- M9 – Theory. Here the physical theory and gas insulated systems with SF_6 is explained.
- M10 – Life Cycle Assessment. Here the impact for the lifetime of GIS is explained.
- M11 – Future Development. Here the next steps in development are explained for GIS.
- M12 – GIS Specification. Here the rules and conditions for correct specification of GIS are explained.
- M13 – GIS Monitoring. Here the monitoring systems for control and supervision are explained.
- M14 – Gas Handling. Here details of correct gas handling when dealing with SF_6 are given.
- M15 – Digital Communication IEC 62271-3. Here the impact of digital communication in substations is explained.
- M16 – Revision of C37.122 GIS. Here information of the latest revision of the GIS standard is given.

1.1.4 Tutorials and Panels Given

The tutorial and panel sessions have been given 22 times through 2011 at various locations in the United States of America, India, and South America (see Table 1.3). The tutorials have attracted over 700 participants in small (10 attendees) and larger (100 attendees) groups over the last ten years.

To present the complete set of the modules it would be necessary to have a tutorial lasting two or three days, which is considered to be too long and inconvenient for most of the engineers to attend. Thus, the decision was made to combine all the tutorial information in a GIS Handbook that can be consulted by the designers and users at their convenience.

1.2 Definitions

This GIS Handbook is based on definitions used in IEEE and IEC standards. Some of the most important definitions for better understanding of the book are listed below.

1.2.1 GIS

There are two definitions used in IEC "Gas Insulated Switchgear" and IEEE "Gas Insulated Substations." The reason has an historical background, where IEC started in SC 17A to develop circuit breaker standards and later started a new subcommittee SC 17C on high voltage switchgear assemblies, so the link was made to switchgear. In IEEE, the substation committee developed standards on GIS in the substation subcommittee, so the link of GIS was taken to substations.

In IEEE C37.122:

Gas insulated switchgear (GIS): a compact, multicomponent assembly, enclosed in a grounded metallic housing in which the primary insulating medium is SF6 and which normally includes buses, switches, circuit breakers, and other associated equipment.

Table 1.3 Conferences where the tutorials have been presented

Conference	Location	Year	Attendance
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	35
IEEE PES El Salvador Chapter	San Salvador, El Salvador	June 2013	40
IEEE PES CATCON	Kolkata, India	December 2013	55
T&D Conference and Exhibition	Chicago, USA	April 2014	63
		Total	1018

In IEC 62271-203:

Metal-enclosed switchgear and controlgear: switchgear and controlgear assemblies with an external metal enclosure were intended to be earthed, and complete except for external connections. There is no specific definition of GIS.

1.2.2 Metal-Enclosed Switchgear and Controlgear

Switchgear and controlgear assemblies with an external metal enclosure were intended to be earthed and complete except for external connections, as defined in IEC 62271-203.

1.2.3 Gas Insulated Metal-Enclosed Switchgear

Metal-enclosed switchgear in which the insulation is obtained, at least partly, by an insulating gas other than air at atmospheric pressure, as defined in IEC 62271-203. This term generally applies to high voltage switchgear and controlgear. Three-phase enclosed gas insulated switchgear applies to switchgear with the three phases enclosed in a common enclosure.

Single-phase enclosed gas insulated switchgear applies to switchgear with each phase enclosed in a single independent enclosure.

1.2.4 Gas Insulated Switchgear Enclosure

Part of the gas-insulated metal-enclosed switchgear retaining the insulating gas under the prescribed conditions necessary to maintain the highest insulation level safely, protecting the equipment against external influences and providing a high degree of protection to personnel, as defined in IEC 62271-203.

In IEEE C37-122, a grounded part of the gas insulated metal-enclosed switchgear assembly retaining the insulating gas under the prescribed conditions necessary to maintain the required insulation level, protecting the equipment against external influences and providing a high degree of protection from an approach to live energized parts.

1.2.5 Compartment of GIS

A section of a gas insulated switchgear assembly that is enclosed except for openings necessary for interconnection provides insulating gas isolation from other compartments. A compartment may be designated by the main components in it, for example, circuit breaker compartment, disconnect switch compartment, bus compartment, and so on, as defined in IEEE C37.122.

A compartment of GIS as defined in IEC 62271-203 as part of a gas insulated metal-enclosed switchgear, is totally enclosed except for openings necessary for interconnection and control.

A compartment may be designated by the main component contained therein, for example, circuit breaker compartment or bus bar compartment.

1.2.6 Design Pressure of Enclosures

The maximum gas pressure to which a gas insulated switchgear enclosure will be subjected under normal service conditions, including the heating effects of rated continuous current, as defined in IEEE C37.122.

1.2.7 Gas Monitoring Systems

Any instrumentation for measuring, indicating, or giving remote warning of the condition or change in condition of the gas in the enclosure, such as pressure, density, moisture content, and so on, as defined in IEEE C37.122.

1.2.8 Gas Leakage Rate (Absolute)

The amount of gas escaping by a time unit expressed in units of Pa m^3/s, as defined in IEEE C37.122.

1.2.9 Gas Leakage Rate (Relative)

The absolute leakage rate related to the total amount (mass or volume) of gas in each compartment at the rated filling pressure (or density). It is expressed in percentage per year, as defined in IEEE C37.122.

1.2.10 Gas Pass Through Insulator

An internal insulator supporting one or more conductors specifically designed to allow the passage of gas between adjoining compartments, as defined in IEEE C37.122.

1.2.11 Gas Zone

A section of the GIS, which may consist of one or several gas compartments that have a common gas monitoring system. The enclosure can be single-phase or three-phase, as defined in IEEE C37.122.

1.2.12 Local Control Cubicle (or Cabinet) (LCC)

A cubicle or cabinet typically containing secondary equipment including control and interlocking, measuring, indicating, alarm, annunciation, and mimic one-line diagrams associated with the primary equipment. It may also include protective relays if specified by the user.

1.2.13 Support Insulator

An internal insulator supporting one or more conductors, as defined in IEC 62271-203.

1.2.14 Partition

Part of an assembly separating one compartment from other compartments. It provides gas isolation and support for the conductor (gas barrier insulator), as defined in C37.122.

A partition as defined in IEC 62271-203, which is a support insulator of gas insulated metal-enclosed switchgear separating one compartment from other compartments.

1.2.15 Power Kinematic Chain

A mechanical connecting system from and including the operating mechanism up to and including the moving contacts, as defined in C37.122.

1.2.16 Design Pressure of Enclosures

Relative pressure used to determine the design of the enclosure. It is at least equal to the maximum pressure in the enclosure at the highest temperature that the gas used for insulation can reach under specified maximum service conditions. The transient pressure occurring during and after a breaking operation (e.g., a circuit breaker) is not to be considered in the determination of the design pressure, as defined in IEC 62271-203.

1.2.17 Relative Pressure across the Partition

Relative pressure across the partition is at least equal to the maximum relative pressure across the partition during maintenance activities. The transient pressure occurring during and after a breaking operation (e.g., a circuit breaker) is not to be considered in the determination of the design pressure, as defined in IEC 62271-203.

1.2.18 Operating Pressure of Pressure Relief Device

Relative pressure chosen for the opening operation of pressure relief devices, as defined in IEC 62271-203.

1.2.19 Routine Test Pressure of Enclosures and Partitions

Relative pressure to which all enclosures and partitions are subjected after manufacturing, as defined in IEC 62271-203.

1.2.20 Type Test Pressure of Enclosures and Partitions

Relative pressure to which all enclosures and partitions are subjected for type test, as defined in IEC 62271-203.

1.2.21 Rated Filling Pressure p_{re}

Insulation and/or switching pressure (in Pa), to which the assembly is filled before putting into service. It is referred to at the standard atmospheric air conditions of +20 °C and 101.3 kPa (or density) and may be expressed in relative or absolute terms, as defined in C37.122.

1.2.22 Bushing

A device that enables one or several conductors to pass through a partition, such as a wall or a tank, and insulate the conductors from it, as defined in IEC 62271-203.

1.2.23 Main Circuit

All the conductive parts of gas insulated metal-enclosed switchgear included in a circuit that is intended to transmit electrical energy, as defined in IEC 62271-203.

1.2.24 Auxiliary Circuit

All the conductive parts of gas insulated metal-enclosed switchgear included in a circuit (other than the main circuit) intended to control, measure, signal, and regulate. The auxiliary circuits of gas insulated metal-enclosed switchgear include the control and auxiliary circuits of the switching devices, as defined in IEC 62271-203.

1.2.25 Design Temperature of Enclosures

Maximum temperature that the enclosures can reach under specified maximum service conditions, as defined in IEC 62271-203.

1.2.26 Service Period

The time until a maintenance, including opening of the gas compartments, is required, as defined in IEC 62271-203.

1.2.27 Transport Unit

Part of gas insulated metal-enclosed switchgear suitable for shipment without being dismantled, as defined in IEC 62271-203.

1.2.28 Mixed Technologies Switchgear (MTS)

Mixed technology switchgear concerns the following combinations:

AIS in compact and/or combined design
GIS in combined design
Hybrid IS in compact and/or combined design
As defined in CIGRE Technical Brochure of Study Committee B3 Working Group 20 from November 2008

1.3 Standards and References

1.3.1 Standards

Standards are valuable documents that allow the manufacturer to develop equipment to meet the majority of user applications, and users to specify equipment that meets their needs in most cases. There are always cases that fall outside typical cases covered by standards, but they are few. Although there are many national and regional standards, the primary standards that apply to GIS are the International Electro-technical Committee (IEC) and the Institute of Electrical and Electronic Engineers (IEEE) standards. In recent years, great effort has been made to harmonize these standards. This effort continues, but differences between them remain. These reflect the differences in the nature of systems, applications, and practices between different parts of the world.

Gas insulated switchgear, components, and related equipment fall under a large number of standards. Both IEC and IEEE standards have standards for GIS, circuit breakers, switches, bushings, testing, instrument transformers, controls, cabinets, pressure vessels, and so on. The difference in the equipment built under the two sets of standards is small and an understanding of how the equipment is designed and tested can usually allow the user to specify equipment under either set of standards. Most manufacturers design the equipment to meet either set of standards, but often limits on testing capability or cost can leave some areas covered by one set of standards only. This requires some examination of the requirements of the application and the tested performance of the equipment to determine if it meets the requirements. There has been, and continues to be, efforts made in the standards community to harmonize the requirements between IEEE and IEC. For high voltage GIS, efforts on 62271-203 and recently C37.122 (2010) have resulted in a high level of harmonization. Progress has also been made on high voltage circuit breaker standards, but here many differences remain. Still, by understanding the differences, a user can use either standard.

An example of differences between IEEE and IEC GIS standards is in North America, where safety requirements for maintenance personnel mandate a visible break to verify that the circuit is not energized before it can be approached for maintenance. This requires a view port or camera to verify the disconnect switch blade position. In other countries, safety requirements allow verification of the position of the disconnect switch linkage to confirm that the switch is open.

There are standards other than IEEE and IEC that cover requirements related to GIS, for example, the American Society of Mechanical Engineers (ASME), the American Society for Testing and Materials (ASTM), the European Committee for Electrotechnical Standardization (CENELEC), European Standards (EN), the National Electrical Manufacturers Association (NEMA), and so on.

1.3.2 Current Standards Most Relevant to GIS

The following is a listing of the most relevant standards that may be used for specification of a GIS. This listing was developed in 2012. Historically, standards can be withdrawn or their numbering changed, but usually only every decade or so.

1.3.2.1 General

IEEE C37.122: IEEE Standard for Gas-Insulated Substations
IEEE C37.123: IEEE Guide to Specifications for Gas-Insulated, Electric Power Substation Equipment
IEEE C37.122.1: IEEE Guide for Gas-Insulated Substations
IEEE C37.1300: Cable Connections
IEC 62271-203: Gas-Insulated Metal-Enclosed Switchgear for Rated Voltages above 52 kV
IEC 62271-1: Common Specifications
CIGRE Brochure 125: User Guide for the Application of Gas-Insulated Switchgear (GIS) for Rated Voltages of 72.5 kV and Above

1.3.2.2 GIS Enclosures

In some jurisdictions in the United States, local building codes require the use of the following standards for GIS enclosures:

ANSI/ASME Boiler and Pressure Vessel Code, Section VIII: Pressure Vessels, Divisions 1 and 2
ANSI/ASME B31.1: Power Piping

The ASME standards are not specifically intended for use for electrical enclosures, but are required in local building codes and are therefore relevant.

In Europe and in Canada, the standards developed by the European Committee for Electrotechnical Standardization (CENELEC) for GIS enclosures are commonly used:

CENELEC EN 50052: Specification for Cast Aluminum Alloy Enclosures for Gas-Filled High-Voltage Switchgear and Controlgear
CENELEC EN 50064-1989: Specification for Wrought Aluminum and Aluminum-Alloy Enclosures for Gas-Filled High-Voltage Switchgear and Controlgear
CENELEC EN 50069: Specification for Welded Composite Enclosures of Cast and Wrought Aluminum Alloys for Gas-Filled High-Voltage Switchgear and Controlgear
CENELEC EN 50089: Specification for Cast Resin Partitions for Metal-Enclosed Gas-Filled High-Voltage Switchgear and Controlgear

In other regions often other standards are in place for GIS enclosures.

1.3.2.3 GIS Systems Above 52 kV

IEEE C37.122: Standard for High Voltage Gas-Insulated Substations Rated above 52 kV
IEC 62271-203: High-Voltage Switchgear and Controlgear – Part 203: Gas-Insulated Metal-Enclosed Switchgear for Rated Voltages above 52 kV

1.3.2.4 Gas-Filled Bushings

IEEE Std. C37.017: IEEE Standard for Bushings for High Voltage Circuit Breakers and Gas Insulated Switchgear
IEC 61462: Composite Hollow Insulators – Pressurized and Unpressurized Insulators for Use in Electrical Equipment with Rated Voltage Greater than 1000 V – Definitions, Test Methods, Acceptance Criteria and Design Recommendations
IEC 62155: Hollow Pressurized and Unpressurized Ceramic and Glass Insulators for Use in Electrical Equipment with Rated Voltages Greater than 1000 V
IEC 60507: Artificial Pollution Tests on High-Voltage Insulators to be Used on a.c. Systems

1.3.2.5 Common Clauses for Switchgear

IEEE Std. C37.100: IEEE Standard Definitions for Power Switchgear
IEEE Std. C37.100.1: IEEE Standard of Common Requirements for High Voltage Power Switchgear Rated above 1000 V
IEC 62271-1: High-Voltage Switchgear and Controlgear. Part 1: Common Specification

1.3.2.6 Sulfur Hexafluoride Gas

ASTM D2472-00: Standard Specification for Sulfur Hexafluoride
IEC 62271-303: Use and Handling of Sulfur-Hexafluoride (SF_6)
IEC 60376: Specification of Technical Grade Sulfur Hexafluoride (SF_6) for Use in Electrical Equipment
IEC 60480: Guidelines for the Checking and Treatment of Sulfur Hexafluoride (SF_6) Taken from Electrical Equipment and Specification for its Re-use

1.3.2.7 High Voltage Testing on Control Systems

IEEE Std. C37.90.1: Surge Withstand Capability (SWC) Tests for Relays and Relay Systems Associated with Electric Power Apparatus
IEC 61180-1: High-Voltage Test Techniques for Low-Voltage Equipment – Part 1: Definitions, Test and Procedure Requirements
IEC 61180-2: High-Voltage Test Techniques for Low-Voltage Equipment – Part 2: Test Equipment

1.3.2.8 High Voltage Circuit Breakers

IEEE Std. C37.04: IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers Rated on Symmetrical Current Basis
IEEE Std. C37.06: High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis: Preferred Ratings and Related Required Capabilities
IEEE Std. C37.09: IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis
IEC 62271-100: High-Voltage Switchgear and Controlgear – Part 100: High-Voltage Alternating-Current Circuit-Breakers
IEC 62271-101 High-Voltage Switchgear and Controlgear – Part 101: Synthetic Testing

1.3.2.9 Disconnect and Grounding (Earthing) Switches

IEEE GIS switches are included in IEEE Std. C37.122 (previous IEEE GIS switch standard C37.38 has been withdrawn)

IEC 62271-102: High-Voltage Switchgear and Controlgear – Part 102: Alternating Current Disconnectors and Earthing Switches

1.3.2.10 Safety and Grounding

ANSI/IEEE C2: National Electrical Safety Code

IEEE Std. 80: IEEE Guide for Safety in AC Substation Grounding

IEEE Std. 367: IEEE Recommended Practice for Determining the Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault (ANSI)

1.3.2.11 Application Guides for Circuit Breakers

IEEE Std. C37.010: IEEE Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis

IEEE Std. C37.011: IEEE Application Guide for Transient Recovery Voltage for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis

IEEE Std. C37.012: Application Guide for Capacitance Current Switching for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis

IEEE Std. C37.015: IEEE Application Guide for Shunt Reactor Current Switching

CIGRE 304: Guide for the Application of IEC 62271-100 and IEC 62271-1. Part 1: General Subjects

CIGRE 305: Guide for the Application of IEC 62271-100 and IEC 62271-1. Part 2: Making and Breaking Tests

1.3.2.12 Application Guides for GIS

CIGRE 125: User Guide for the Application of Gas-Insulated Switchgear (GIS) for Rated Voltages of 72.5 kV and Above

IEEE Std. 1300: IEEE Guide for Cable Connections for Gas-Insulated Equipment

1.3.2.13 Application Guides for SF_6

CIGRE 234: SF_6 Recycling Guide

CIGRE 276: Guide for the Preparation of Customized Practical SF_6 Handling Instructions

IEEE 1125: IEEE Guide for Moisture Measurement and Control in SF_6 Gas-Insulated Equipment

IEEE Std. 1416: IEEE Recommended Practice for the Interface of New Gas-Insulated Equipment in Existing Gas-Insulated Substations

1.3.2.14 Reliability Evaluations

CIGRE 83: Final Report of the Second International Inquiry on High Voltage Circuit-Breaker Failures and Defects in Service

CIGRE 150: Report on the Second International Survey of High Voltage Gas-Insulated Substations (GIS) Service

CIGRE 319: Circuit-Breaker Controls, Failure Survey on Circuit Breaker Control Systems

1.3.2.15 Cable Terminations and Connections

ANSI/NEMA CC 1: Electric Power Connection for Substations
IEEE Std. 48: IEEE Standard Test Procedures and Requirements for Alternating-Current Cable Terminations 2.5 kV through 765 kV
ANSI Std. C63.2: American National Standard Specifications for Electromagnetic Noise and Field-Strength Instrumentation, 10 kHz to 40 GHz.
IEC 61639: Direct Connection between Power Transformers and Gas-Insulated Metal-Enclosed Switchgear for Rated Voltages of 72.5 kV and Above

1.3.2.16 Seismic Design

IEEE Std. 693: IEEE Recommended Practices for Seismic Design of Substations
IEC 60068-3-3: Environmental Testing – Part 3: Guidance. Seismic Test Methods for Equipment

1.3.2.17 Control Cabinets

IEC 62262: Degrees of Protection Provided by Enclosures for Electrical Equipment Against External Mechanical Impacts (IK code)
ANSI/IEC 60529: Degrees of Protection Provided by Enclosures (IP code)
NEMA 250: Enclosures for Electrical Equipment
IEEE Std. C37.21: IEEE Standard for Control Switchboards
IEEE Std. C57.13: IEEE Standard Requirements for Instrument Transformers
IEEE Std. C37.24: IEEE Guide for Evaluating the Effect of Solar Radiation on Outdoor Metal-Enclosed Switchgear
IEEE C37.301: Standard for High-Voltage (above 1000 V) Test Techniques – Partial Discharge Measurements
IEEE Std. C62.11: IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (>1 kV)
IEEE Std. 4: IEEE Standard Techniques for High-Voltage Testing
IEEE Std. 315: IEEE Standard, American National Standard, and Canadian Standard Graphic Symbols for Electrical and Electronics Diagrams (Including Reference Designation Letters)

ASTM publications are available from the Customer Service Department, American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103, USA.

CENELEC publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

IEC publications are available from IEC Sales Department, Case Postale 131, 3 rue de Varembe, CH-1211, Geneva 20, Switzerland/Suisse. IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

CIGRE publications are available from CIGRE, 21 rue d'Artois, 75 008 Paris, France.

ANSI Standards are available from the American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

1.4 Ratings

1.4.1 General

The purpose of ratings is to correctly apply GIS equipment based on electiric system topology and characeristics while reducing the variety of technical possibilities and guiding manufacturers. These ratings provide standardized solutions that are recognized across the industry and reduce cost. The main ratings are voltage, insulation level, frequency, current, short time and peak withstand current, duration of short circuit and auxiliary voltages, and frequencies.

In high voltage switchgear, the rating structures are defined for devices such as circuit breakers, and disconnect switches, grounding (earthing) switches, and connecting conductors/bus. In general, they are covered in IEEE C37.100.1 or in IEC 62271-1 for switchgear products.

For assemblies of high voltage switchgear like GIS, the ratings in the standards are adopted to design criteria and applications in the field. The design of GIS has to take into account that the development and manufacturing cost of the metallic enclosures as pressure vessels of the GIS are very high. For this reason, some designs of GIS are grouped to cover multiple voltage ratings. One technical criterion of the equipment, for example, rated voltages of 110 kV, 123 kV, 138 kV, and 145 kV, is covered by the same class of GIS with the same enclosure. Within this range of voltage classification, only different gas densities of SF_6 differentiate between the different voltage levels. In terms of current ratings, the difference between 2000 A, 2500 A, and 3000 A might only be a different number of contact fingers or different wall thicknesses of conductors.

1.4.2 Rated Maximum Voltage

The high voltage (HV) levels in standards start at ratings above 52 kV in both IEC and IEEE standards. Below these voltage levels, the equipment is classified as medium voltage (MV). The typical GIS high voltage ratings can be grouped into four design classes or equipment types for any manufacturers, even if the split may vary somewhat. The lower high voltage ratings are in the range from 52 kV to 72.5 kV as the first level range. The second level range of ratings includes 100 kV, 123 kV, 145 kV, and, in some manufacturers' design, also the 170 kV rating within the same GIS type. The third level range of ratings covers 245 kV and 300 kV with one GIS type. The fourth level range of ratings includes the voltages 362 kV and 420 kV with the same GIS type. The 345 kV voltage level is considered as 362 kV and is no longer recommended by standards today. The third and fourth level ranges have been historically developed in North America and Europe, typically 245 kV and 420 kV in Europe and 300 kV and 362 kV in North America. The reason behind this is the availability of technical solutions like insulators at the time when the new voltage levels were established. An overview of the voltage ratings is given in Table 1.4.

There are only two rated voltages left in the IEEE and IEC standards, which have two different options for power frequency switching and lightning impulse values, which are 245 kV and 362 kV. The 550 kV rated voltage offers two insulation levels for the rated power frequency withstand voltage.

1.4.3 Rated Insulation Level

The ratings for insulation levels are derived from the network to which the GIS is connected. Network conditions, like lightning strokes into overhead lines, their local probability, and their expected strength, are indicators for the overvoltages that may occur. In the case of cable

Table 1.4 Rated voltages of IEEE and IEC

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

networks, the length of cables and their related overvoltages during switching operations will influence this rating.

Rated insulation levels are key parameters for the design of GIS and do have a direct impact on the enclosure diameter and, with this, a high cost impact in development and manufacturing cost. Each rated voltage in IEC and IEEE has the choice of two or even more insulation levels. In GIS, the choice is usually made in favor of the highest requirement for the GIS.

As shown in Table 1.4, in most cases the listed rated power frequency withstand voltage, the rated switching impulse withstand voltage, and the rated lightning impulse withstand voltage for the related rated maximum voltage is the highest value from IEC and IEEE standards. Only the rated maximum voltage classifications of 245 kV and 362 kV have the choice of two voltage levels. The reason behind these choices is that, in North America, many such GIS are in operation from the past, while the rated insulation levels of today's GIS offer higher values.

1.4.4 Rated Power Frequency

The most used power frequencies for GIS are 50 Hz originated in Europe and 60 Hz originated in North America. Apart from 16 ⅓ Hz and 25 Hz for railroad applications, the majority of GIS applications are with 50 Hz and 60 Hz. These two frequencies are distributed world-wide and form regions and countries with one or the other frequency. Some countries, for example, Japan and Saudi Arabia, have both frequencies.

The dielectric impact to the GIS design of these frequencies is negligibly low. The thermal impact needs to be considered when the current rating is approaching the limits, because at 60 Hz the power density is higher and, with this, the thermal rise. Temperature limits should not be exceeded because of possible damage to insulators or contact systems.

Table 1.5 Typical current ratings of GIS related to voltage classes

5000–8000 A				x	x	x
4000–5000 A				x	x	x
3150–4000 A			x	x	x	
2500–3150 A		x	x	x		
1250–2500 A	x	x				
	52–72.5 kV	**100–170 kV**	**245–300 kV**	**362–550 kV**	**800 kV**	**1100 kV**

1.4.5 Rated Continuous Current

The continuous current rating is a basic design criterion of GIS for contactors and contact dimensioning. The complex structure of GIS allows close influence of the different devices such as circuit breakers, ground switches, disconnect switches, current transformers, voltage transformers, and bus bars in terms of heat dissipation and temperature rise. For this reason, the IEEE and IEC standards require temperature rise tests to confirm the correct function of all devices included in GIS. A so-called typical bay configuration will be used for this test.

One of the factors specific to a GIS installation may show that the rated continuous current may be different for the busbar or the feeders depending on the substations' scheme. Typical rated continuous currents are shown in Table 1.5.

1.4.6 Rated Short Time Withstand Current

The rated short time withstand current (I_K), the peak withstand current (I_p), and the duration of the short circuit (t_K) are basic dimensioning parameters for GIS design (see Table 1.6).

These values have a great impact on the electromechanical forces to the insulators and conductors, and on the thermal rise, mainly of the contact system. These values are also tested by specific type tests to confirm the satisfactory function of the different devices of a GIS, such as the circuit breaker, disconnect, ground switch, and bus bars.

1.4.7 Rated Peak Withstand Current

The rated peak withstand current (I_p) is defined by the DC time constant of the network. The rated peak withstand current is defined as a factor of the rated short time withstand current. Typical values in the network are 45 ms in most voltage classes, and up to 120 ms in ultra high voltage (UHV) networks. The related factors are shown in Table 1.7.

GIS equipment is designed to fulfill these requirements.

Table 1.6 Typical short-circuit current ratings of GIS related to voltage classes

63–100 kA				x	x	x
50–63 kA			x	x	x	x
31,5–50 kA		x	x	x		
25–31.5 kA		x	x			
16–25 kA	x					
	52–72.5 kV	**100–170 kV**	**245–300 kV**	**362–550 kV**	**800 kV**	**1100 kV**

Table 1.7 Typical factors to calculate rated peak withstand currents (I_p)

Networks	Factor to calculate I_p	DC constant
50 Hz up to 500 kV	2,5	45 ms
60 Hz up to 500 kV	2,6	45 ms
50/60 Hz 800 kV and above	2,7	60 ms, 75 ms, 120 ms

1.4.7.1 Rated Duration of Short Circuit

The rated duration of a short circuit (t_K) depends on the network protection and is symmetrical. Over the decades of network development, and with increasing short circuit ratings, this value has developed to shorter times. A typical value today is 1 s, but also 0.5 s can be used. In some cases, 2 s or 3 s may be required. The duration of a short circuit has a significant impact on the GIS design, and it is recommended to keep this time as short as possible (see Table 1.8).

1.4.8 Rated Supply Voltages

There are many different supply voltages used and covered by the standards. This high variation is costly for substation design and should be reduced. Therefore, the standards give some preferred values. For existing substations, this might not be economical but new substation design should follow these recommendations (see Table 1.9).

Table 1.8 Rated duration of short circuit (t_K)

	Rated duration of short circuit (t_K)
Short	0.5 s
Standard	1.0 s
Long	2.0 s
Very long	3.0 s

Table 1.9 Rated supply voltages

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