

Gas Insulated Transmission Lines – Successful Underground Bulk Power Transmission for more than 30 Years

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Abstract

Gas Insulated Transmission Lines (GIL) are a means of bulk electric power transmission at extra high voltage. GIL consists of tubular aluminium conductors encased in a metallic tube that is filled with a mixture of Sulphur Hexafluoride and Nitrogen gases for electrical insulation.

Since the first installation of GIL in 1975, second generation GIL has been developed that is more economically viable and its design optimised both for installation and operation.

Where GIL is installed in combination with Gas Insulated Switchgear (GIS), compact solutions can be delivered in order to supply large amounts of electric power to meet the high demand of large cities and industry. These new possibilities can mitigate power flow problems, reduce the risk of failure of electrical transmission systems and enable the installation of optimum solutions regarding technical, economical and environmental aspects.

1. Concept of GIL

Gas Insulated Transmission Lines (GIL) are a means for bulk power transmission at extra high voltage (EHV), e.g. 400kV, with rated currents up to 4000A. Similar to bus sections and the busbar arrangements on GIS, GIL principally consists of tubular Aluminium conductors. Fig 1 shows a cross section of a three phase GIL arrangement in a tunnel.



Fig 1: GIL cross section (3 phases)

The inner conductor is at the high voltage level. The outer casing is usually grounded and serves as encapsulation. For insulation purposes, the pipes are filled with a mixture of

nitrogen and the insulation gas, sulphur hexafluoride (SF₆) which has been applied in the sector of high voltage engineering very successfully for several decades. Table 1 shows the most important technical data.

Rated voltage	230 kV – 550 kV
Rated current	2500 A – 4000 A
Transmission capacity	1000 MVA – 3800 MVA
Rated short-time current	63 kA/3s
Rated Frequency	16 $\frac{2}{3}$ Hz railways, 50/60Hz
Capacitance	55pF/m
Inductance	220nH/m
Resistance	10m Ω /km (typical)
Insulation gas	N ₂ -SF ₆ mixture
Pipe materials	Aluminium alloys

Table 1: Technical data of GIL

GIL does not generally compete with overhead lines (OHL) but is applied as a means of power transmission where OHL cannot or must not be applied, such as, densely populated areas or in environmentally sensitive regions. Additionally, due to their outstanding advantages, GIL may be applied where the application of cables are not possible or where they reach their technical limits. The most important advantages GIL has to offer are:

- High transmission capacity
- Low transmission losses
- Low capacitance
- High reliability
- High operational safety (no fire risk, no external impact in case of internal failure)
- Applicability of automatic reclosure
- No practical ageing of components (long lifetime)
- Very low external magnetic fields

Due to the low capacitance GIL may be applied to lengths up to 100km without the need for reactive compensation measures. The very low magnetic fields allow a routing in populated areas without violating the lowest limits of magnetic flux densities. The gaseous insulation allows long lengths without reactive compensation and enables automatic reclosure. In a similar sense to GIS [1] there is no technical ageing of the components applied to GIL therefore there is no lifetime limit for GIL once they are properly installed.

2. Two generations of GIL

The very first Siemens GIL was installed from 1973 – 1975 in the Black Forest in Germany. The German utility Schluchseewerk AG expanded its power generating capacity by the installation of the pumped storage power plant “Wehr”. This plant is equipped with four motor-generator sets which are situated underground in a cavern [2]. The generators feed into a remote overhead line on the 400kV system via transformers rated at 21/410kV which are also situated in the cavern. The connection from the transformers to the remote OHL is via GIL which runs through a tunnel of approximately 600m in length. The main issues considered for GIL or cable were availability, technical issues and safety requirements gained through the experience from a cable fire in a different power plant which occurred previously [3]. This was more so relevant because of the 190m difference in height from the bottom of the tunnel to the top and risk of fire propagating upwards through the tunnel. Ultimately, predominantly technical advantages and the economically justifiable efforts were decisive for choosing GIL [3, 4, 5], which was the first installation of its kind. Fig 2 shows the GIL double circuit in the tunnel.

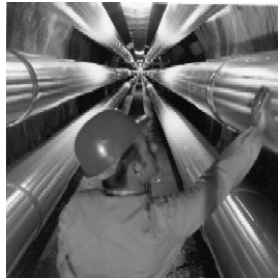


Fig 2: GIL double system at the Wehr power plant

After the Wehr project further installations of the 1st generation GIL followed. However, most of them were special applications in power plants or substations. During the 1990s EDF of France initiated the discussion about the feasibility of a large scale application of GIL with the intention of grid expansion. For such purposes the costs of GIL had to be reduced significantly in order to enable an application on a large scale. From experience and knowledge gained through the 1st generation GIL, Siemens developed the 2nd generation of GIL during the 1990s which resulted in a cost reduction of more than 50% when compared to the original design [6]. In addition to the cost reduction, the 2nd generation of GIL offers additional features such as flexible installation possibilities enabled by the possibility to bend the GIL and the reduction in the use of SF₆ gas by developing a combination of SF₆ and N₂. The differences between the 1st and 2nd generation GIL are listed.

1st Generation

- pure SF₆
- aluminium pipes with straight beads
- 9m long transport units

- hand welding
- application of disc spacers only
- special design for each project

2nd Generation

- N₂-SF₆ gas mixture
- spiral welded aluminium pipes
- transportation units between 11.5m and 13.5m
- automated orbital welding
- ultrasonic welding control procedure
- bending of the whole tube possible to radii > 400 m
- application of particle traps all along the pipes
- application of support insulators
- modular design with a few standardized modules
- state-of-the-art monitoring systems

Fig 3 shows a cross section of the second generation of GIL including the support insulators and the particle trap.

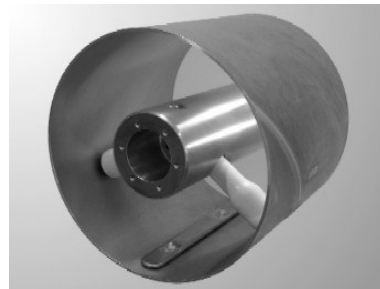


Fig 3: Cross section of the 2nd generation of GIL

3. Operating experience

The installation in the Black Forest was commissioned in 1975. In 2002, after 25 years of operational experience, the utility reported that the experiences gained with the installation are very good [7] since no major issues had occurred during operation.

Five years after commissioning, in 1980, after a severe thunderstorm both systems were switched off. This was the result of an extremely strong lightning strike, with a magnitude far in excess of 100kA that hit the OHL and caused a back-flashover at the 5th tower. The large size of the encapsulated surge arresters at that time inhibited their installation at the transformer; instead they had to be positioned 30m away, inside the cavern. Outdoor surge arresters were installed at the interface from GIL to OHL. Due to the disadvantageous position of the encapsulated arrester, a flashover occurred between the transformer and the arrester inside the GIL. As a consequence, the insulation co-ordination between OHL and GIL was improved by the installation of another set of surge arresters and despite many further lightning strikes no further flashovers have occurred to date [7].

The first installation of the 2nd generation of GIL was commissioned in January 2001 in Geneva, Switzerland [8]. This GIL was installed in a tunnel that replaced an existing OHL section of approximately 400m in length. This was necessary since the Palexpo exhibition centre was extended with another exhibition hall which was erected where the OHL was located. The main reasons for choosing GIL was its resultant low magnetic interference level, the high transmission capacity and the reduced heating effect [8]. The GIL section is inserted in the 11km long OHL between Verbois and Foretaille. The whole line including the GIL is covered with high speed automatic reclosure without any further devices such as circuit breakers, disconnectors or current transformers at the interface between OHL and GIL. Figures 4a and 4b show the two sets of GIL tubes inside the tunnel and the OHL connection of the installation



Fig 4a: Tunnel installed GIL in Geneva



Fig 4b: OHL/GIL interface in Geneva

The operating experience of the past 5 years has been very good. There have been no reported SF6 gas leaks and the heat dissipation in the tunnel is minimal.

The monitoring system was a new development for the 2nd generation of GIL and shortly after commissioning a few improvements were required for minor teething problems that could not have been detected in the laboratory during development. After the eradication of these the system has since operated without further problems.

4. Innovative Monitoring Systems

For the monitoring of GIL various control systems are available. As standard, GIL systems are equipped with Gas monitoring system and an Arc-Location-System (ALS) Both systems were applied at the Geneva installation. The standardised gas monitoring system consists of gas density monitors for each separate gas compartment. If the gas pressure inside one compartment falls below an adjustable threshold a warning signal occurs. In case the pressure continues to fall an alarm will be activated. The data of the density monitors are transferred to the control station via data buses.

The Arc Location System allows the location of an internal flashover with a range accuracy of some 10 meters. In case an internal arc causes damage that requires repairing the position of the defective section can be ascertained quickly and easily. The ALS is based on the analysis of the runtime differences of Very Fast Transient (VFT) signals at different positions. For this, Arc Location Converters (ALCs) are positioned at regular distances. Fig 5 shows the principal structure and the working principle of the ALS. The data transfer takes place via optical fibres.

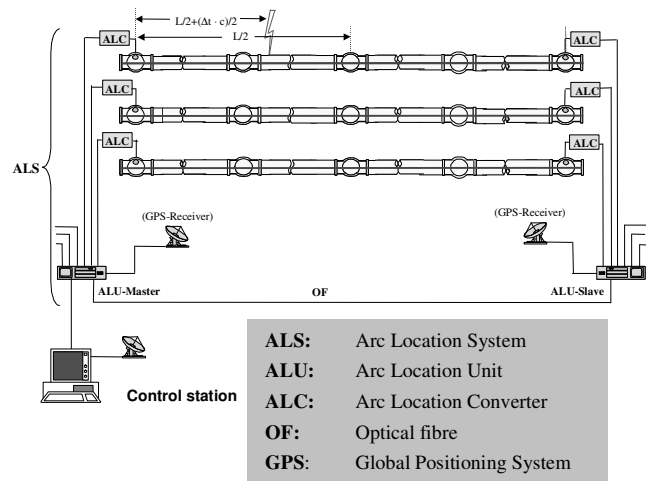


Fig 5: Principle of the Arc Location System

On request, GIL can also be equipped with additional monitoring systems which enable the acquisition of comprehensive information about the condition of the GIL and which allows the operator to exploit the maximum transmission capacity; these include Gas Pressure Monitoring GPM, Partial Discharge (PD) Monitoring and Thermal Rating System.

The GPM applies pressure sensors which allow a very precise measurement of the gas pressures of the individual gas compartments. The measured data are transferred to the control station by data buses. This way, the exact pressure of each gas compartment can be displayed and stored at a central computer allowing long term trend analyses by which the smallest gas losses can be determined. GPM can also be combined with density monitors that allow compensation for

fluctuations in gas temperature eliminating false readings of gas pressure.

During commissioning high voltage tests with accompanying PD measurements take place in the individual GIL sections by monitoring Ultra High Frequency (UHF) signals that result under the presence of partial discharge. During operation of the GIL the UHF sensors monitor PD measurements and compare these with values taken during commissioning which are stored and used as set points. Similar to Gas Insulated Switchgear (GIS) or Highly Integrated Switchgear (HIS) the PD activity of the GIL can be measured during operation and stored to provide data that can be used toward the assessment of the dielectric strength of the insulation.

The components used with GIL, e.g. conductors, sliding contacts, connections etc., are designed for a maximum rated current of 4000A. However, this is dependent on the installation conditions and in reality the permissible normal rated current is below 4000A due to the maximum permissible temperatures of conductor and enclosure pipes that have a limiting effect on the maximum current. Usually the load on transmission lines is not continuous but varies during the day. GIL can, therefore, be overloaded above the permissible normal rated current up to 4000A for a certain length of time depending on the thermal conditions. For such a controlled overloading of GIL a thermal rating system can be applied. This system measures the temperatures of the conductor and the enclosure pipes as well as monitoring all relevant boundary conditions (e.g. air temperature, solar radiation, wind velocity etc.). With this data the actual temperatures of the pipes can be displayed and the future temperatures can be forecast depending on the actual and intended load.

The measurement of the conductor temperatures can be made with infrared sensors which are applied accordingly [9]. The signals of all the sensors can be transferred easily to the control station. Fig 6 shows an example for the data acquisition for a gas density monitor and a temperature sensor for the conductor. Due to modern communication techniques the data can be transferred to almost any spot around the world so that remote control of the system is possible.

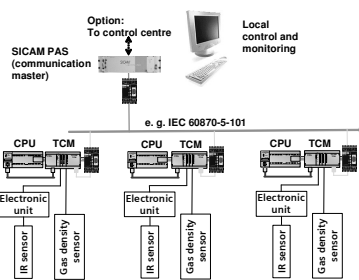


Fig 6: Data acquisition

5. GIL in combination with Highly Integrated Switchgear (HIS)

The design of modern high voltage substations has changed compared to those erected half a century ago. The main drivers are of technical, economic and environmental issues but new designs have also allowed project managers and operators to improve flexibility, efficiency, environmental integration and the adaptability of installations [10]. In addition, quicker installation and commissioning procedures, coupled by the highest guarantees of reliability are demanded. These new drivers arose because of the trends in electric power supply over the recent decades were mainly dominated by reduced space, environmental impact, increasing power transmission, life cycle cost evaluations and asset management [11].

In more recent years, therefore, a growing demand for compact solutions for indoor as well as outdoor solutions has been experienced [10] leading to the development of particular solutions by switchgear manufacturers. Siemens combined the high reliability of gas insulated switchgear (GIS) and the high maintainability of air insulated substations (AIS) to produce Highly Integrated Switchgear (HIS) for outdoor applications. Pre-fabricated HIS modules are delivered from the manufacturing plant to site. The modular design reduces the overall time for installation and commissioning drastically compared to AIS [12]. The pre-fabrication of modules reduces the risk of faulty installations on site. Due to good accessibility HIS has short repair times and due to its high reliability the availability of HIS is much higher than AIS. The modular design of HIS enables innovative service concepts that allow fast and efficient replacement of HIS bays [12] or their reconfiguration. Additionally, the service intervals of HIS are significantly higher than those of comparable AIS substations. Due to the application of gas insulated equipment, compared to conventional air insulated technology, space savings of up to 70% may be achieved by installing HIS. The operating costs of HIS are lower than with AIS and as a consequence, the life cycle costs comprising investment and operational costs of HIS are lower than those of AIS [10]. Fig 7 shows a 400kV HIS installation in Spain.



Fig 7: HIS installation in Spain (400 kV, commissioned 2005)

Similar to HIS, GIL of the second generation was developed to enable utilities to cope with the new challenges of the power transmission industries. The modular designs of GIL, GIS and HIS allow an arbitrary combination of these techniques. These equipment types can also be connected

easily to overhead lines (OHL) or transformers so that for each project the best arrangement can be found, both, from the technical and the economic view points.

In 2004, 400kV switchgear for National Grid (NG) was erected and commissioned at Elstree substation, London. It is a combination of GIS, HIS and GIL. Fig 8 shows the HIS with the connected GIL (bare aluminium pipes) whereas Fig 9 shows the GIL connecting the outdoor HIS with the indoor GIS.



Fig 8: Outdoor HIS with connected GIL



Fig 9: GIL connecting HIS and GIS in outdoor installation

6. Future perspectives

GIL is a means of bulk power transmission. Its flexibility allows installations above ground, in tunnels or directly buried. Due to the very low magnetic fields and due to the lack of a fire risk GIL enables totally new possibilities for the routing of EHV transmission lines. GIL can be routed right into or through conurbations and residential areas without violating limits for magnetic fields allowing electrical power to be transmitted right into the centre of conurbations on the EHV level which is typically 400kV in Europe. In addition, with GIL a diagonal connection of OHL rings around major cities are possible. These new possibilities can mitigate power flow problems and reduce the risk of the failure of electrical transmission systems [13].

7. Conclusion

The requirements to installations for high voltage power transmission and distribution have changed. HIS and GIL as innovative products offer new possibilities to cope with these new requirements. Depending on each situation, by a coordinated application of the different techniques of GIS, HIS, AIS, OHL and GIL the optimum solution will be provided regarding technical, economical and environmental aspects.

8. References

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