Experience with 2nd Generation Gas-Insulated Transmission Lines GIL

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Abstract: The Gas-Insulated Transmission Lines (GIL) of the second generation are now in services since more than 2 years, with very good service experiences. The 2nd generation GIL is insulated with N_2/SF_6 gas mixtures and the design and laying technique is primary dedicated to long distance transmission lines.

The paper gives examples of the key experiences for long distances applications and shows future possibilities where GIL is the best technical solution. New applications of GIL as a high power transmission line used together with public accessible tunnels like train or street tunnels will be explained. Also the application of special energy tunnels over long distances will be explained.

Keywords: Gas-Insulated Transmission Line (GIL) - Tunnel Laid - PALEXPO - Sai Noi - Design and Layout of GIL - High Power Transmission - Long Length

Résumé: Les Lignes de transport à Isolation Gazeuse (LIG) de seconde génération sont maintenant en service depuis plus de deux ans et l'expérience recueillie en exploitation est très bonne. L'isolation de cette seconde génération de LIG est réalisée au moyen de mélanges gazeux N2/SF6. La conception et les techniques de pose sont essentiellement consacrées aux lignes de transport sur de grandes distances.
Ce rapport donne des exemples d'expériences clés concernant des applications longue distance et dégage les possibilités futures où la LIG constitue la meilleure solution technique. Il fournit des explications au sujet de nouvelles applications de la LIG en tant que ligne destinée au transport de grandes quantités d'énergie, installée dans des tunnels accessibles au public tels que des tunnels ferroviaires ou routiers. Il explicite également l'emploi de galeries dédiées pour le transport d'énergie électrique sur de grandes distances.

Mots clés: Ligne de transport à isolation gazeuse (LIG) – Pose en tunnel – PALEXPO – Sai Noi – Conception et implantation de LIG – Transport de grandes quantités d'énergie électrique – Grandes distances

1. Introduction

With the commissioning of the 500 m long gas-insulated transmission line (GIL) at the Geneva Airport, Siemens is the first manufacturer of the second generation GIL world-wide. This project concluded successfully the recent development works on this future transmission technology. The redesign of GIL brought a reduction of costs by more than 50 %. The main changes were replacing pure SF_6 by a gas mixture of N_2 and SF_6 as insulating medium and by adopting pipeline laying methods into the laying process.

Based on the now more than 30 years of experience in gas-insulated high voltage technology the redesign of the first generation GIL installed in 1974 at the Hydro Power Plant Wehr in Germany was started in 1995 with a first feasibility study together with EDF [1].
In the following for both types (directly buried and tunnel-laid) a prototype set-up was built at IPH, an independent test lab in Berlin. The development and test program have been carried out in co-operation with three major German utilities. The main intentions of the tests were to simulate the electrical and mechanical stresses of a lifetime of more than 50 years

and to prove the assembly and laying process under on-site conditions. Both types of GIL, directly buried and tunnel laid, passed the tests successfully without any technical problem and without any time delay. The GIL of the second generation is now certificated. The assembly and laying was carried out under real in-site conditions and are proved laying techniques. The GIL is qualified as a long distance power transmission system laid in a tunnel or directly buried, so that distances of 100 km and more are possible to build [2, 3].

The N_2/SF_6 gas mixtures are used in high voltage switchgear since many years in extreme low temperature regions around the world with very positive experiences. The design criteria for the gas mixture to find an optimum between gas pressure, dimensioning and N_2/SF_6 mixture percentages.

The main advantages of the GIL compared to other transmission systems, overhead lines and cables are the capability of very high power transmission ratings due to the low resistive losses, very low electromagnetic field, no risk of fire or external harm and no need for reactive power compensation.

The GIL in Geneva, Switzerland, at the PALEXPO exhibition area, is a typical future application where an existing 300 kV overhead line was replaced by an underground GIL laid in a tunnel to give space for expansion of a PALEXPO exhibition hall. The GIL in this case is only used for power transmission as part of an important overhead line connecting France with Switzerland [4, 8].
The complete manufacturing, laying and on-site testing process has been carried out in the same way as it is planned to do with long distances GIL. The experiences in all steps of the process are very positive including the management of obstacles and unforeseen situations [4].

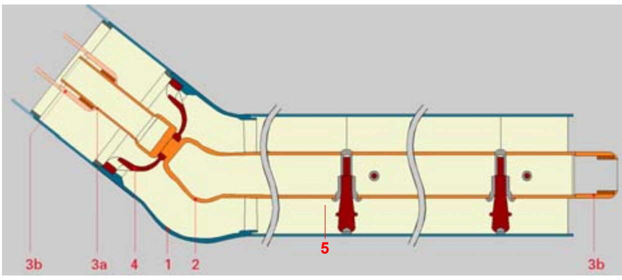
A second project now in service in Bangkok, Thailand, at the Sai Noi substation is typical for the very high power transmission capability of the GIL with a rated current of 4000 A. At a rated voltage of 550 kV this allows a transmitted power of 3800 MVA with one three-phase system.

The extreme external conditions of very high ambient temperature, the extreme sun radiation and the high rated current of this important power supply line of Bangkok shows the high power transmission capability of GIL.

In both cases assembly and laying technologies were used which have been developed to install long lengths of GIL lines up to some hundred kilometres at economical cost levels for high power ratings.

2. Technical Data and Basic Design

The basic design of the GIL is shown in Fig. 1 - as a general example - a straight unit combined with an angle unit. In the single-phase enclosure made of aluminium alloy (1), the inner conductor (2) is fixed by a conical insulator (4) and rests on support insulators (5). The thermal expansion of the conductor with respect to the enclosure will be compensated for by the sliding contact system (3a, 3b). The straight units are welded together by orbital welding machines. If a directional change is needed with more than what the elastic bending of the straight units can take care of, then an angle element will be added, covering angles from 4 to 90°. For longer GIL applications, disconnection units are placed at distances of 1.2 to 1.8 km. Such units are used to separate gas compartments and to connect high-voltage testing equipment for commissioning of the GIL. The compensator unit is used to absorb thermal expansion of the enclosure.



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

Fig. 1: Straight construction unit with an angle element

The main technical data of the GIL for the 420 kV transmission network as well as for the PALEXPO project are shown in Table 1. For 550 kV networks, the SF_6 content must be increased in order to meet the higher required rated withstand voltages.

Table 1: Technical data of the GIL

Type	**Design**	**Project**
Nominal voltage	420 kV	300 kV
Nominal current	3150 A/ 4000 A	2000 A
Lightning impulse volt.	1425 kV	1050 kV
Switching impulse volt.	1050 kV	850 kV
Power frequency volt.	650 kV	460 kV
Rated short time current	63 kA/3 s	50 kA/3 s
Rated gas pressure	7 bar	7 bar
Insulating gas mixture	80 % N_2, 20 % SF_6	80 % N_2, 20 % SF_6

The rated values shown in Table 1 are chosen for the requirements of the high-voltage transmission grid of overhead lines. The power transmission capability of the tunnel-laid GIL allows the maximum power of an overhead line to continue underground without any power transmission reduction. Surge arresters are used at the GIL terminations.

For monitoring and control of the GIL, secondary equipment is installed for measurement of the gas density.

An electrical measurement system is used to detect arc location. Very fast transient electrical signals are measured at the ends of the GIL and the position of a very unlikely internal fault will be calculated with an accuracy of $\pm$ 25 m.

3. Main Design Feature

The re-design of the gas-insulated transmission technology GIL of the second generation reached an overall cost reduction, compared to the first generation of more than 50 %. To reach the goal the following steps were taken: limiting the variety to only 4 modules, reducing the number of elements of each module by high standardised elements, use of long lengths of each module of typical 12 to 20 m, using Nitrogen N_2 as the major insulation gas, development of an automated orbital welding machine, solid grounded enclosed pipes lead to very low magnetic fields, and adapting the laying methods of the oil and gas pipelines to the needs of high voltage equipment.

In the following some main design features of the GIL are explained in more detail [5, 6, 7].

3.1 N_2/SF_6 Gas Mixture

Nitrogen N_2, Sulphurhexafluorid SF_6, and the mixtures of both are insulating gases known and used since many decades for high voltage equipment. N_2/SF_6 gas mixtures are in use since the 1970ies in high voltage equipment for low temperature application with no problems reported. So the experience with gas mixtures is very positive. In the case of GIL no arc quenching capability as used in circuit breakers or disconnectors is used, only insulating purpose. This allows to reduce the SF_6 content of values which are in the range of 10 % - 20 % of the gas mixture, without increasing too much the dimensions and the gas pressure. The filling pressure of the GIL is 0,7 MPa which is the same as for high voltage circuit breakers, where the good experience is available. The dimensions of the GIL are chosen with the premises to limit the maximum electrical field strength in GIL to values below those of today's high voltage equipment. In a 550 kV GIL the maximum field strength is below 3.5 kV/mm. This low electric field strength makes the GIL a very reliable system, as the more than 30 years of experiences with Gas-Insulated Switchgear and Lines (GIL) shows. World-wide more than 150 km are installed and no major failure has been reported.

3.2 Orbital Welding

To connect each GIL unit in the past flanges with bolts and hand welding was used on site. For shorter lengths this joint technology is appropriate, but if tens of kilometres need to be built a more automated system is needed. The main reason for this is that a high rating of repetitive quality must be reached, not to delay the speed of laying. Integrated in the automated welding is also a 100 % ultrasonic quality check of the weld. The combination of automated orbital welding and an automated ultrasonic quality check of each weld have been positive proven in the project at PALEXPO, Geneva, and Sai Noi, Bangkok, with a more than 99 % first pass yield. The orbital welding head is shown in Fig. 2 while welding the conductor.

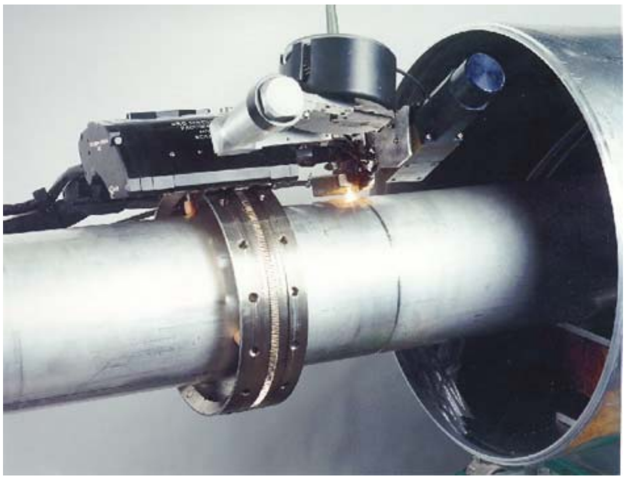


Fig. 2: Orbital welding of the conductor

3.3 Magnetic Fields

The GIL is operated as a solid grounded system. Each GIL segment is grounded by contacting the enclosure with the steel structure supporting it. The steel structure then is connected to the tunnel grounding and each of the 3phase enclosures are connected with each other. The low electrical impedance of the enclosure pipe, due to its big cross section, allows a current induced in the enclosure as high as the conductor current. The induced electrical current in the enclosure is 180° phase shifted to the conductor current. The result of the addition of the magnetic field of the conductor current and the enclosure current is the effective magnetic field which is reduced by more than 99 %. This makes the GIL to a transmission system with very low magnetic fields in the surrounding.

Even with high currents of 3150 A the low values of 1 µT, which are required in Switzerland in areas where public access is given, can be reached close to the GIL system. At PALEXPO less than the required value was measured on the floor of the exhibition hall about 4 m above the GIL.

4. Applications

4.1 PALEXPO, Geneva, Switzerland

The first application of the 2^{nd} generation of GIL has been carried out between September and December 2000. Only in 3 months erection time the overhead line was brought underground into a tunnel and connected to the net again in January 2001. In Fig. 3 a site view shows the delivery of GIL transport units to the preassembly area.

Fig. 3: Delivery of transport unit to the preassembly area

The preassembly tent has been placed directly under the overhead line and was positioned directly above the shaft connected to the tunnel right under the street. The narrow space between an airport access road on one side and the highway to France on the other side makes it only possible to use the space directly under the overhead line for the site works. The laying procedure had proven to be applicable also for long distance connections. With the site experience the productivity for assembling the GIL sections could be very much increased from 2 connection per shift and day to 4 connections per shift and day. These are very positive experiences for future projects, especially if very long distances for GIL links have to be carried out. The highly automated laying process had proven to deliver a very constant quality over the complete laying time so that the commissioning of the system could be carried out without any failure.

In Fig. 4 a view into the tunnel shows how the pipes are pulled into the tunnel. The tunnel has a bending radius of about 700 m. The pipes were easily moved over support structures with rollers and follow the bending of the tunnel.

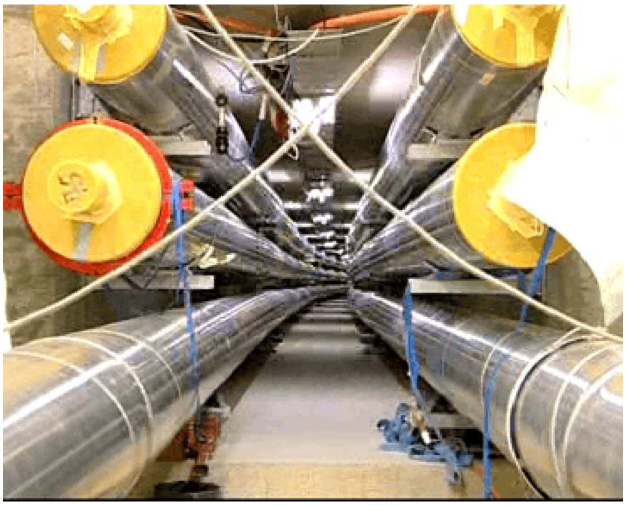


Fig. 4: Pulling the GIL into the tunnel

4.2 Sai Noi

The Sai Noi substation is an important station for the Bangkok power supply. An extension of an existing Gas-Insulated Substation (GIS) required also some long connections between the existing GIS, an existing AIS and the new extended GIS. About 1 km of system length or 3 km of pipe length had to be installed for this reason.

The requirements to the transmission had been high. At a rated voltage of 550 kV a rated current of 4000 A was needed to fulfil the requirements of the transmission lines connected to this substation. At the same time the ambient air temperature was as high as 50 °C at the same time the direct sun radiation was high too. The GIL can fulfil all these requirements and the operation started successfully in September 2002. The overview about the GIL installation is given in Fig. 5.

The GIL at Sai Noi has been installed according to the same procedures as installed in the PALEXPO project in Geneva, Switzerland. The methods of orbital welding, gas mixture, on-site GIL segment assembly and the pulling method haven been applied.

Fig. 5: Above ground installed GIL in Sai Noi, Bangkok (550 kV/4000 A)

4.3 Project Experiences

The experiences made with the laying methods of the second generation GIL have been only positive.
The concept of on-site assembly with delivery of components directly to the site assembly has proven as good. This way of assembling the GIL has a high flexibility towards any task coming from the laying process and has been directly solved with the sub-suppliers. The delivery of components like enclosure pipe, conductor pipe, and insulators are ordered in charges for some days on truck delivery to meet the needs of the work in the assembly and welding tent.

The work flow in reality was better and faster than the previously planned time schedule and the working speed could be increased by more than 30 %. Down from the planned 4 months of erection time for the PALEXPO project an erection time including the high voltage testing and commissioning of 2 1/2 months was reached. The final limits of speeding up the laying process came from the fabrication capacity of the subsuppliers, which could not further increase the production of GIL-elements. But this is no limitation in manufacturing of GIL- elements, it is only a question of planning. It is also a very important advantage of the GIL, that the GIL-elements can be produced by many different subsupplier companies around the world in almost any number.

The quality of the assembled GIL was high, even with this up-speeded assembly process. This can be seen that in both projects the 300 kV GIL at PALEXPO, Geneva, and the 550 kV GIL at Sai Noi, Bangkok, have been high voltage tested and went in operation without any failure.

The laying of a high voltage GIL is a team work of different skilled level workers starting from cleaning and handling personnel to mechanical skilled workers and electrical high voltage experts. Most of the works carried out with on-site assembly are relative easy and standard works, like mechanical machinery and welding. Most of the work personnel is local and can be hired at any place in the world. The only experts needed are for the quality check of the weld and the final high voltage proof of the GIL before the welding of the enclosure.

Another very important experience with the GIL projects are the positive results of the high voltage on-site testing. The sensitive partial discharge (PD) measurements using an antenna inside the GIL have proven to be very effective in evaluation of the internal high voltage condition. This resulted in passing the test conditions according to IEC 61640 without failure.

The GIL has also the advantage that the length of the transmission line can be high voltage tested in sections of approximately 1 km. For the high voltage test only an air bushing needs to be connected to the GIL through a connection housing as part of the GIL. In table 2 the requirements to HVAC test systems for 400 kV equipment AC testing shows a comparison of XLPE cables, GIS and GIL. The table was presented by Hauschild during the CIGRE Session 2002 in SC 21.

Table 2: Requirements to HVAC test systems for 400 kV equipment AC testing

	max. load capacitance	test voltage	test frequency	test current	50 Hz equiv. power
XLPE cable	4000 nF (15 km)	260... 400 kV	20...300 Hz (IEC 62067)	200 A	85... 200 MVA
GIS	15 nF (200 m)	650 kV	50...300 Hz (IEC 60517)	3 A	2 MVA
GIL	70 nF (1000 m)	650 kV	30...300 Hz	9 A	10 MVA

4.4 Future Applications

GIL is a new, future orientated technical solution of upcoming requirements in power transmission. The non-availability of right of way for new overhead lines in general and the further increase in demand of electrical energy will generate the need for high power underground transmission, even over long distances of 100 km and more.

This makes the GIL primary not only a competitor to underground solid insulated cables, but more an additive technology. Additive in the way when the needed power transmission is high (2000 MVA and more) and the underground transmission length is getting long.

Two typical examples are given here.

Example 1:

The metropolitan areas are growing world-wide. In the future the majority of the population on earth will be living in cities. Therefore, cities are growing in size and power demand. The dimension of metropolitan areas are reaching diameters of 50 to 100 km with a need of high power underground transmission lines.

The GIL can offer a strong, high power electrical power supply of such metropolitan areas, as it is shown in Fig. 6. The GIL will be laid in electrical energy tunnels having two systems with 2000 MVA

transmitted power in each system. The tunnel is passing in a diagonal, crossing the whole metropolitan area and is then connected to ring.

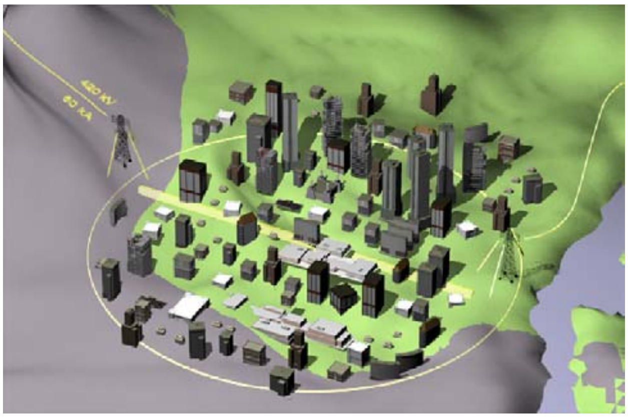


Fig. 6: Power supply of metropolitan areas in the future

Example 2:

The traffic world-wide is increasing. Existing highways are not sufficient to solve the traffic problems of the future. This will lead also to long railroad and street tunnels (see Fig. 7). These tunnels can also be used for electrical energy transmission. The GIL is the only transmission system available which can be added to public accessible tunnels without increasing the risk for persons to be injured if an electrical failure happens in the transmission system. The solid metallic enclosure will keep the impact inside the GIL until the GIL will be switched off by the protection system.

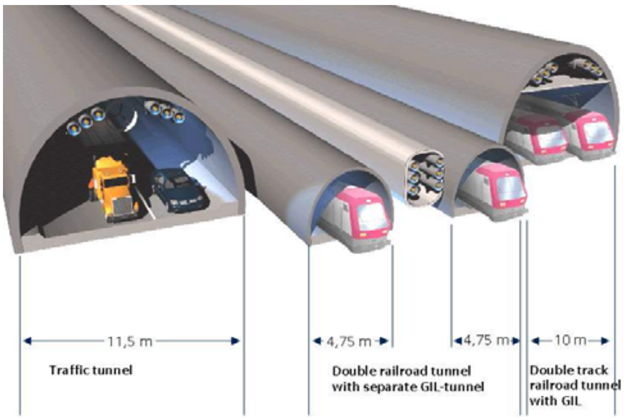


Fig. 7: Typical traffic tunnels for railroad and vehicles

5. Conclusion

The GIL is a high power transmission system designed for the needs of today and the future. The redesign of the gas-insulated technology available and in use since more than 30 years has now led to the 2nd generation GIL. Based on the world-wide experience of more than 130 system kilometres installed GIL of the first generation now the 2nd generation GIL offers gas mixture technology with Nitrogen (N_2) as major insulating gas, fast pipeline type laying technique, very low magnetic fields, and low transmission losses at a more than 50 % reduced price. The first projects of the 2nd generation GIL at PALEXPO in Geneva, Switzerland, and Sai Noi in Bangkok, Thailand, have proven the reliability and availability.

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