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GAS-INSULATED TRANSMISSION LINES - UNDERGROUND POWER TRANSMISSION ACHIEVING A MAXIMUM OF OPERATIONAL SAFETY AND RELIABILITY

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ABSTRACT

Gas Insulated Transmission Lines (GIL) are a means of bulk electric power transmission at high and extra high voltage. GIL consists of tubular aluminium conductors encased in a metallic tube that is filled with a mixture of Nitrogen and Sulphur Hexafluoride gases for electrical insulation.
Apart from other benefits during construction and operation the GIL design offers also in the event of an internal failure the ability to maintain the arc and its product completely within the enclosure, thus delivering a maximum of safety and reliability during operation which qualifies the system for high end engineering solutions. The particular features are discussed regarding the Limberg II project currently being under execution in Austria.

KEYWORDS

power transmission in hydro power plants; gas insulated lines (GIL); operational, constructional and environmental aspects

INTRODUCTION

Gas Insulated Transmission Lines (GIL) are a means of bulk electric power transmission at high and extra high voltage. GIL consists of tubular aluminium conductors encased in a metallic tube that is filled with a mixture of Nitrogen and Sulphur Hexafluoride gases for electrical insulation. Since the first installation of GIL in 1975, second generation GIL has been developed which is more economically viable and its design was optimized both for installation and operation. Where GIL is installed in combination with Gas Insulated Switchgear (GIS), compact solutions can be delivered. As such GIL can contribute in the mitigation of power flow problems, reduce the risks of failure of electrical transmission systems and enable the installation of optimum solutions regarding technical, economical and environmental aspects.
Due to its modular design, a GIL transmission system can cope with difficult installation requirements as well as it offers further benefits to the service after installation. Amongst other matters such as 30 years nearly maintenance free service, particular attention should be drawn on the operational reliability. Wherever bulk power transmission systems are located in galleries or similar structures or close together, a potential fire hazard is of particular concern. Due to its robust metallic enclosure GIL is significantly less affected by a potential fire compared with other power transmission facilities such as cables. On top of that it offers also in the event of an internal failure the ability to maintain the arc and its product completely within the enclosure, thus delivering a maximum of safety and reliability during operation.
The project Limberg II is mainly an extension of the existing hydro power plant close to Kaprun in Austria. Beside the installation of the power generation equipment this project is characterized by a 400 kV GIS located in the cavern and a Gas Insulated Line which connects the GIS with the overhead line on the top of the transition building. Besides its design inherent advantages the most supporting factors in relation to the use of a GIL were its reliability and safety in terms of an operational fire hazard along with the extremely low magnetic field exposure within the gallery during service. As the gallery route follows an inclination of app. 42°, particular attention is to be drawn on the installation procedure and sequence with consequences for the site logistics. The project is currently at the stage of detailed planning and engineering, commencement of site works for the construction of the GIL is expected in 2010 after completion of the gallery and related civil works.

Figure 1: Photo-mounting of pumped-storage plant project Limberg II

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PROJECT DESCRIPTION

The power plant group *Glockner-Kaprun* of *Verbund-Austrian Hydro Power* was erected during the years from 1938 to 1955. The generating capacity of the power plants *Kaprun Hauptstufe* and *Kaprun Oberstufe* was adjusted to the demand of those years and is actually about 350 MW. Additionally, the pumped storage plant *Kaprun Oberstufe* which is located between the large seasonal reservoirs *Wasserfallboden* and *Mooserboden* (81,2 / 84,9 million m^3) is provided with a pumping capacity of 130 MW.

The idea to increase the pumped-storage capacity by an additional power plant between the a.m. reservoirs was already born several years ago. From various versions the project "Limberg II" was selected. Figure 1 schematically shows the upper and lower reservoir with an average height of 360 m, the pressure tunnels with a nominal discharge of 144 m^3/s and the underground power house. By a total nominal load of 480 MW the power output of the plant group will be increased to 833 MW and the pumping capacity will rise to 610 MW.

Due to the location in the high mountains above a sea level of 1.500 m, an underground power plant design with two main caverns was selected. The power cavern will contain two Francis pump-turbines with the respective synchronous motor-generators and the turbine inlet valves and auxiliary equipment. The main transformers, a 420 kV gas insulated switchgear and a SFC starting-facility for the pump turbines will be installed in the transformer cavern. The isolated phase buses with the generator circuit breakers and the phase reversal switches will be located in cross galleries between the main caverns.

The 400 kV GIS in the transformer cavern is connected with the OHL transition building by a gallery which bridges a 80 m difference in altitude by a rampant section. Taking the various aspects into account it was decided to connect the 400 kV GIS with the overhead line by a gas insulated line.

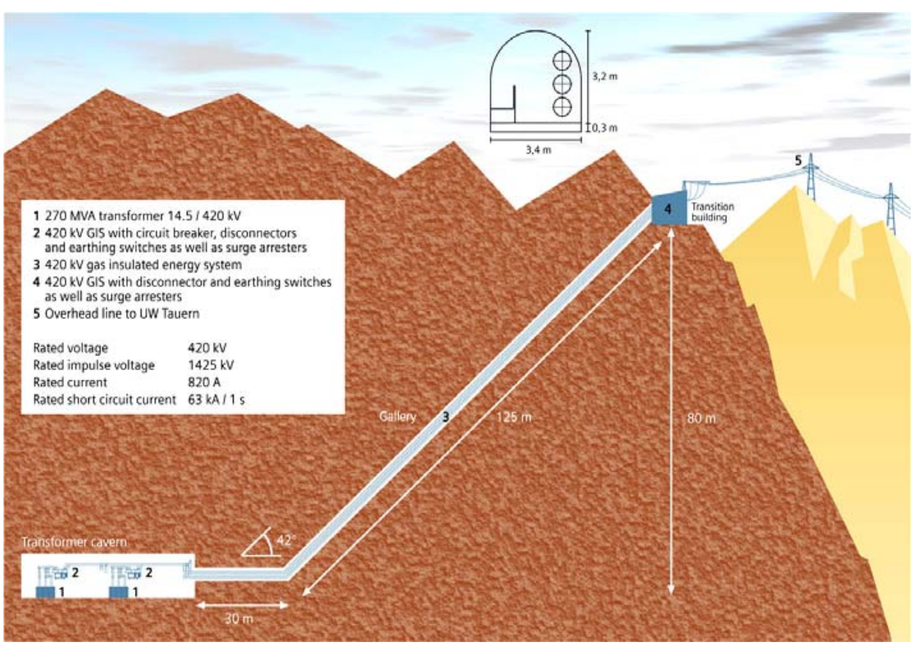

Figure 2: Section View of the GIL Installation

OPERATION-RELATED ADVANTAGES OF GIL

Energy transmission in pumped-storage power plants has been facilitated in the past mainly using high voltage cables in order to avoid complex OHL outdoor installations. When it comes to reliability it is worth mentioning that for 35 years several GIL installations in the voltage range of up to 500 kV have been in service. So far, no single fault has occurred in service due to failure of the insulating gas, nor of the epoxy resin insulators. To date, experience with GIL in service with Siemens amounts to approximately 35 km of phase length. No ageing of gas insulation is evident in GIL.

The outgoing line of the hydro power plant Limberg II will be mainly located in an inclined gallery. The underground section between the GIS in the cavern and the OHL-interface at the surface will be app. 155 m long and has been designed as a GIL application. The connected overhead line provides the link to the network via the substation "UW Tauern". The entire system will work at 380 kV service voltage. Both, the GIS located in the cavern and the underground section of the outgoing line are typical applications for gas insulated power transmission installations. The same applies to the minimised switchgear at the GIL-OHL interface which consists mainly of disconnecting and earthing switches. In case of any leakage the SF6 will be contained at the lowest point in a trap from where it can be taken out in a controlled manner, such as pumping in tanks or bottles. Altogether this installation differs significantly from an installation in the transmission network under conditions of public access. Reasons for the installation of a Gas Insulated Transmission Line in the gallery were in particular:

Electromagnetic compatibility

Low electromagnetic field radiation was envisaged in order to allow service personnel to enter the gallery under full load conditions without time limitation. The value of inductance with GIL amounts to <5 µT in 0.5 m of distance under full load. The comparable value with XLPE cables is significantly higher.

Avoidance of fire hazard in the event of failure

Personal injury has to be avoided under any circumstances in the gallery even in case of an internal fault. No burn through of GIL housings has to be considered within 500 ms of arc quenching time. Furthermore the amount of inflammable material installed in the gallery will be reduced to a minimum. Therefore no additional fire protection has to be provided with GIL. In case of cables, the construction of a fire protection wall, segregating the tunnel into two sections along the route, would have been required. This in turn would have led to significantly higher cost for the construction of the gallery.

Continuity of gas insulated technology from the OHL interface up to the transformers

The consequent application of gas insulated components avoids multiple transfers from one insulation technology to the next and back. As transition means such as cable terminations are avoided, which in turn increases the reliability of the system. Statistics demonstrate that the majority of failures during service, which have not been imposed externally, frequently involve equipment which is designed for the transition between different insulation technologies.

Fully encapsulated design

The design of the GIL provides a 100% metallic, grounded encapsulation. Due to this, the electrical field strength outside the GIL will be zero at any point and at any time. As such there will be no limitations imposed during service even in case of staff being present in the gallery. This fact is important for the use of the GIL gallery for access and emergency exit purposes.
In the event of cable failure, the installation of repair joints would not be possible due to the small dimensions of the gallery. A 4th reserve phase would have to be laid. With GIL, only 3 phases have to be installed in the gallery, keeping the size of the gallery small.

Commissioning test

The HV commissioning test can be performed together with the GIS test procedure. The relatively compact test equipment can be transported through the gallery.

Environmental and operational aspects

"Global warming friendly design" is ensured through total gastight welding of all tubes. No servicing is envisaged over lifetime; no refilling of gas mixture is necessary. The leakage rate lies one order of magnitude below the GIS standard of 0.5 % p.a. /1/. Moreover the GIL tubes are filled with a gas mixture of 80% N2 and 20% SF6 in order to keep the amount of SF6 low. This is feasible due to the electro negativity of SF6 comprising high electric breakdown strength even at low concentration of SF6.

Line Autoreclosure

Autoreclosure functionality "Off-On-Off" in case of failure is applicable with GIL. This feature is an important issue as the extension of the outgoing system is a 380 kV overhead line to the substation "UW Tauern". The autoreclosure will now cover the entire line from the GIS through GIL section and overhead line to the substation "UW Tauern". As autoreclosure cannot be applied for a section built from power cables, segregation into zones with and without autoreclosure capability would be required.

MODULES OF GIL

The GIL system is made from 3 single phase encapsulated pipe modules which are installed on structures in the gallery. The GIL design is based on the following modules:

- straight welded tube module
- straight single flanged tube module
- straight double flanged tube module
- elbow module
- expansion joints
- N2/SF6 – gas mixture as insulating gas and gas monitoring system

Straight welded tube module

Conductor (Figure 3, pos 2)

The conductor must have a low resistance for low transmission losses as well as high mechanical strength. Therefore it is made of extruded aluminium alloy, which combines both properties. The conductor is of tubular design. As the current flow in service (AC-duty-type) occurs mainly in the outer parts of a circumferential cross section, no solid type is necessary. The interior is filled with N_2/SF_6-gas-mixture to achieve a simple construction. The individual conductor- sections are generally jointed by welding.

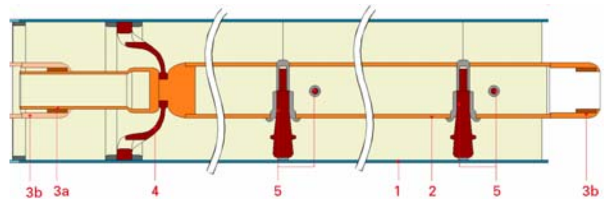

Figure 3: Schematic view of a straight welded tube module

Enclosure / Tube (Figure 3, pos 1)

The enclosure is a pressure-resistant housing for the insulation gas and takes up all loads as bearing-, cantilever- and short-circuit-forces. The suitable material is also aluminium alloy. The individual enclosure-sections are generally jointed by welding to guarantee 100%-gas-tightness and the required mechanical strength.

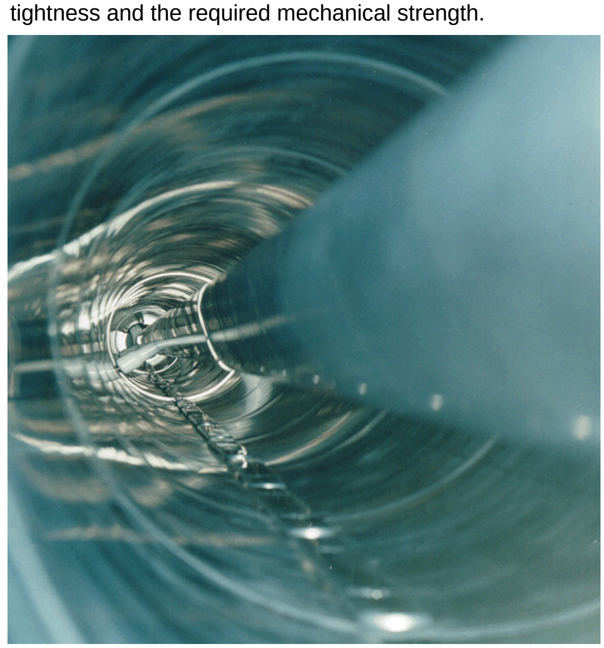

Figure 4: Straight welded tube module with particle trap

Particle Trap

On the bottom of the enclosure housing the particle trap is located, which provides a field less space. Despite all cleanliness measurements particles may occur in the GIL. Due to the influence of the electric field and under the gravity any particle will move underneath that particle trap. Thereby the particle will be neutralised, before it will have any negative influence on the dielectric strength of the GIL. Respectively the particle trap enhances the reliability of the GIL.

Support Insulator/Post Insulator (Figure 3, pos 5)
In a distance of approximately 12m pairs of support insulators made of epoxy cast-resin are arranged in an obtuse angle and thus keeping the conductor centred in the enclosure housing. They are fixed to the conductor and slide on the inside of the enclosure housing to compensate the different thermal expansions of conductor and enclosure housing.

Bushing (Figure 3, pos. 4)
The bushing made of epoxy cast-resin is used as a fixed point for the conductor and tightens in regular distances the conductor position to the enclosure housing, i.e. the conductor will be kept in axial direction and be prevented from torsion. The bushing is fixed to the conductor as well as to the enclosure. These bushings may be either gas-tight or perforated and have the ability to withstand mechanical stresses.

Sliding contact (Figure 3, pos 3a, b)
A sliding contact system is installed at each fix point in order to compensate the differences of thermal expansion between conductor and enclosure housing. The many years proven multi-segment-contacts with silver plated contact surfaces are applied.

Straight single flanged respectively double flanged tube module

Only in the case of connecting an elbow or a expansion joint the straight single flanged respectively double flanged tube module will be used. The flanges of both modules are jointed by means of bolts using the many years proven O-ring / flange-technique known from the Siemens-GIS.

Elbow modules

Elbow modules are made of cast aluminium. All angles from 4° to 90° are possible. The jointing will be made by flanges.

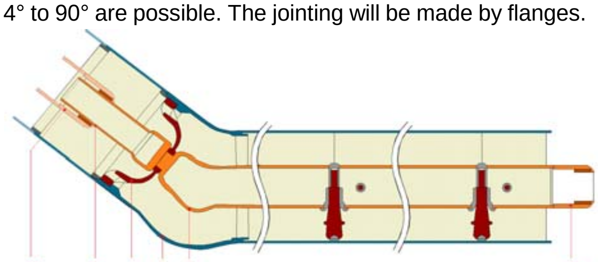

Figure 5: Schematic view of an elbow module

Expansion joints

The expansion joint takes up the thermal expansion of the enclosure housing. This compensator consists of a high-grade-steel-corrugated-tube, which is tightened by steel bonds to take up forces of the gas-pressure. Additionally small shaft settlements and assembly tolerances are compensated in angular direction. External flexible copper-ties ensure the electrical bonding of the bellow, so that the circulating current in the GIL enclosure housing is able to flow continuously and an impermissible temperature rise of the expansion joint is avoided.

In the actual project Limberg II the generated energy is led by one SF6-insulated transmission system rated 420 kV from the GIS to the overhead line. The difference in altitude of the route amounts to 80 m. The shortest and therefore also the most cost-effective route for the energy system is to connect the GIS in one line to the overhead line. While leaving the transformer cavern the routing of the energy system run first horizontally by about 30 m. The route continues with a 42°-slope over a distance of 120 m and ends at the OHL interface building at an altitude of 1626 m. The total system length amounts to about 155 m.

The manufacturing and pressure testing of the housings comply with the European standards, and further relevant pressure vessel codes. The basic modules for this project will be pre-assembled on site, then arranged to the final position and jointed by welding or flanging. A complete quality insurance plan is followed during assembling and laying in order to guaranty fast installation progress and an excellent reliability of the entire system.

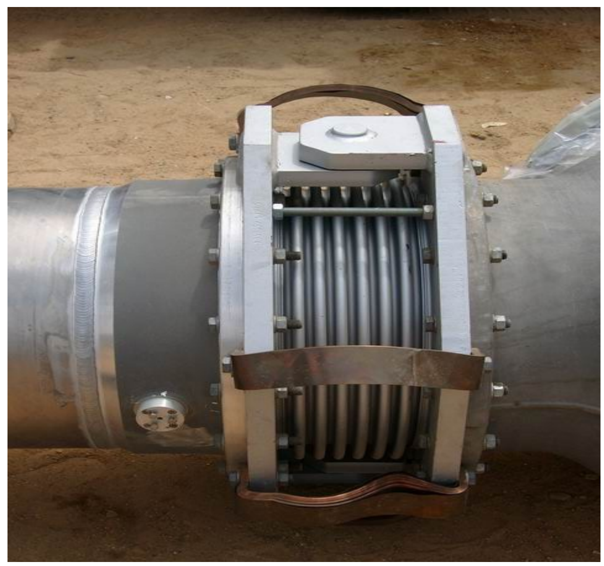
Figure 6: Compensation module

INSULATING GAS AND GAS SUPERVISION

N2/SF6 Gas Mixture as Insulating Gas for GIL

GIL installations require a considerably amount of gas for insulation purposes. Pure SF6 is a very expensive gas. On top of that the use of SF6 is to be limited to the required minimum for environmental reasons as SF6 has a noteworthy green house potential. International researches of Institutes and manufacturers have shown that there exists an alternative to pure SF6 for insulation purposes: a mixture of Nitrogen (N2) and SF6. This saves cost without reducing the reliability of the system. For 400 kV systems the SF6-portion is reduced to 20%. In case of a 550 kV GIL application the percentage SF6 equals 60%. This approach allows limiting the use of SF6 to its technically feasible minimum, thus reducing effectively the green house potential of the gas insulation.

Besides the gas mixture improves the arc burn-trough resistivity of the GIL, because the arcing behaviour in that gas mixture is different to pure SF6. Tests performed with an arcing current of 63 kA, 0.5 s proved, that there is no burn-through of the enclosure housing. Furthermore the erosion of the enclosure housing was limited, because the footprint area of the arc, is larger compared to that one in pure SF6.

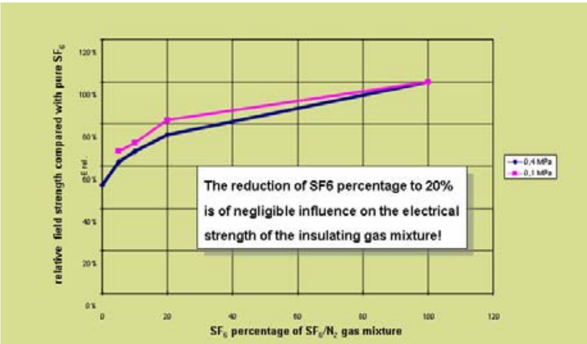

Figure 7: Dielectric Strength of SF_6/N_2 mixture vs. SF6 percentage of the insulating gas

Gas Monitoring

Traditionally GIL Monitoring system has been developed by Siemens during the development of underground transmission technology. The GIL Monitoring is applied for the following 3 installation types:

- gallery installation
- above ground installation
- directly buried.

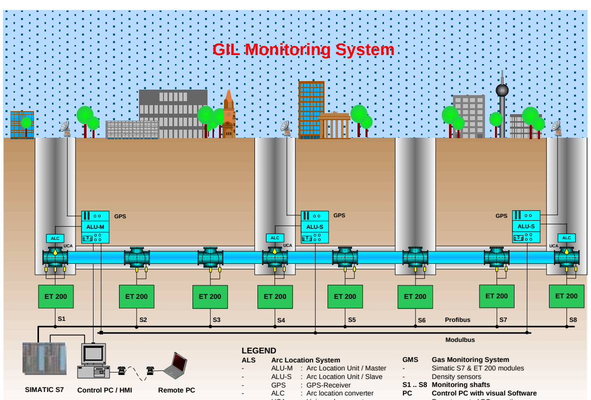

Figure8: GIL monitoring system for long applications

Monitoring is generally adapted to the GIL, pending on the route length different monitoring techniques are used. For short distances below 200 m the monitoring is limited to gas density measurement. In case of longer length an arc location system should be considered. The GIL Monitoring system has the following main functions (see system block diagram in Figure 8):

- Supervision of the N2/SF6 insulating gas density of each gas compartment with density gauges or temperature and pressure sensors irrespectively of the length of the application,
- Detection and location of an internal arc fault, usually applied for longer applications.

The density of the insulation gas mixture of N2 and SF6 is important for the dielectric strength of the system. The integrity of the electrical high voltage system is therefore directly related to the gas density and for this reason a gas density monitoring system is an important part of the GIL. This gas density monitoring is the same as it is used for Gas Insulated Switchgear (GIS). Each gas compartment of the GIL is monitored individually using the density gauges or temperature and pressure sensors.

The GIL is internally divided in individual compartments. For transmission lengths of more than 1000 m the GIL will be separated into sections of gas compartments, which are separated with disconnecting units, see Fig. 1 S1…S5. Each disconnecting unitis equipped with gastight insulators to separate the gas compartments. The density gauges or sensors are installed in the disconnecting unit and connected to the "ET200" modules of the SIMATIC -family, which are linked to a control unit at one end of the GIL system or at the control centre.

If the density of the gas mixture N2/SF6 drops to a defined lower limit, alarm signals will be generated. The gas monitoring system of the GIL is linked to the protection and control system of the connected substations and linked transmission line. The main purpose of the gas monitoring is to protect from system failure like internal arc fault.

Gas tight on-site made connections

A proper, welded connection of two components offers the maximum reliability in terms of gas leakage. Siemens has developed a mechanized orbital welding procedure which ensures that each weld at site will be produced under the same conditions, using identical parameters. This is a prerequisite of high performance welds with a very little requirement of manual corrections and it allows the application of a state of the art quality assurance system.

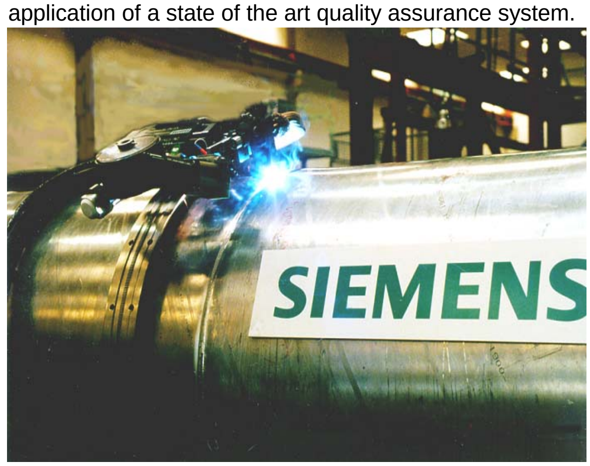

Figure 9: Mechanized Enclosure Welding

The second key point of this system is a 100% ultrasonic test of each weld. Also for this operation an automated and computer controlled ultrasonic test set was developed and recently introduced. As a result the combination of mechanized welding and automated weld testing procedures ensures the high quality of on site welding and leads to site welds which remain tight during the entire life time of the GIL installation. There will be - under normal operation condition- no additional gas filling needed for 40 years of operation of the GIL, apart from the original gas filling at the time of construction. Siemens did construct several welded systems

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during the 70's of the last century such as the installations in Wehr/Germany or Ruacana/Namibia. These systems are in service since that time without any failure or re-filling of gas.

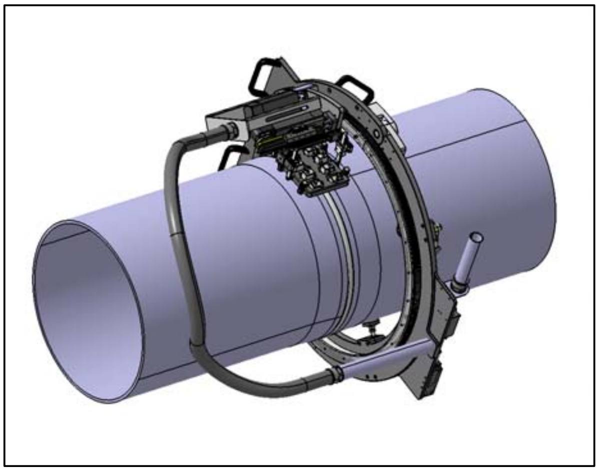

Figure 10: Schematic View of the Mechanised Ultrasonic Test Set

INSTALLATION & COMMISSIONING

Due to the length of the gas insulated energy system it was decided to perform the conductor and enclosure connections by welded seams at the construction site. Exceptions are the 42° angle module and the connections to the GIS modules. The manufacturing processes required for the pre-assembly of the straight modules are carried out in the assembly workshop which is set up in the GIS hall located in the transformer-cavern, where the preparation of welding is done. The cleanness of the inner conductor and the interior of the enclosure are checked carefully and then the inner conductor will be threaded through the enclosure with the help of an assembly device. Now the module is pre-finished and is being transported to the welding area which is located at the beginning of the 42°-slope. There an assembly scaffolding is set up whose work platform can be adjusted on all 3 pipe axes of the sloping route. After the module is correctly levelled the two inner conductors are welded together. Then the two supporting insulators will be inserted and afterwards the two enclosures are shifted together. The next step covers the welding of the enclosures and the performance of the ultrasonic test, which ensures the mechanical strength and the gas tightness of the welding procedure. After the 11.5 m long module is finally assembled and tested it is pulled up by a wrench. This way the modules are mounted together to a total length of about 125 m. Besides the gallery the main assembly areas are the GIS-hall and the transition building where the GIS-modules are installed.

Tests at site

After completion of the assembly work of the 400 kV line a pressure test is carried out phase by phase with clean and dry air considering the necessary security procedures. SF_6 gas and nitrogen are delivered at high purity. In order to avoid pollution it is necessary to well evacuate the gas compartments and to remove the humidity from the pipe

system. Then the two insulating gasses SF6 and nitrogen amixed in the percentage of 20% / 80% and filled into the energy system with an operating pressure of 0.7 MPa. Sniffing of all welded seams and flange joints with a SF6 leak detector shall confirm that no damage occurred after the welds were tested using the ultrasonic system. At the completion of the gas works a dew point measuring and the measurement of the air content of the isolating gas are performed. To proof the demanded dielectric strength of the ready installed 400 kV Gas Insulated Line, an AC high voltage test according to IEC 61640 with 80% of the power frequency withstand voltage level is performed at site. The AC test voltage is provided by a resonance test device which comes along with a temporary PD measurement unit using the UHF method for partial discharge detection.

CONCLUSION

Gas insulated transmission lines are a proven technology for bulk power transmission systems and have a successful operational track during the past 30 years. Welded systems have been operated during this period of time without re-filling of gas or major failures during operation. The permanent supervision of all GIL gas compartments also allows to detect a potential gas leak at a very early stage.
The aspects which led to the application of a gas insulated design for the outgoing line in this project were in particular the low electromagnetic emissions during service and the requirement to keep any fire hazard inside the gallery to a minimum even under the conditions of an internal fault. The continuity of gas insulated technology from the OHL interface up to the high voltage switchgear offers operational advantages. Last but not least the fully encapsulated design contributes to the safety of staff passing the gallery under normal or exceptional operation conditions

LITERATURE

/1/. IEC 62271-203 (November 2004): High-voltage switchgear and controlgear - Gas-insulated metal-enclosed switchgear for rated voltages above 52 kV