21, rue d'Artois, F-75008 PARIS
http : //www.cigre.org

B1-304

CIGRE 2006

ITALY-AUSTRIA GIL IN THE NEW PLANNED RAILWAY GALLERIES FORTEZZA-INNSBRUCK UNDER BRENNER PASS

R. BENATO*, P. BRUNELLO, E.M. CARLINI***, C. DI MARIO***, L. FELLIN*, G. KNOLLSEISEN♦, M. LAUßEGGER♦♦, M. MUHR♦, A. PAOLUCCI*, W. STROPPA♦♦, H. WÖRLE♦♦, R. WOSCHITZ♦**

***Department of Electrical Engineering– University of Padova**
****Department of Fisica Tecnica– University of Padova**
*****TERNA Rete Trasmissione Nazionale – Rome**
♦Department of High Voltage Engineering – Graz University of Technology
♦♦TIWAG-Netz AG – Thaur
ITALY-AUSTRIA

SUMMARY

The paper deals with the possibility of installing a double-circuit **G**as **I**nsulated transmission **L**ine (GIL) in the pilot tunnel of the new planned railway galleries Fortezza-Innsbruck. The high GIL power ratings with very low power losses would allow a strong and highly efficient energy exchange particularly useful for the future European Market and could represent a new fundamental step in reconstructing the European interconnection network. Two separate railway tunnels ($\Phi \approx$ 9,6 m) will run under the Brenner Pass from Fortezza (Italy) to Innsbruck (Austria) but will be preceded by the construction of a continuous pilot tunnel ($\Phi \approx$ 4,3 m) useful for work logistics and chiefly for detection of the rock stratigraphy. Once the whole work will be over, the pilot tunnel will be used as a service gallery (drainage of water) where a double-circuit GIL can be efficiently installed. The paper gives the main characteristics of planned galleries, several details on the transmission line and its performance, the electro-magnetic field impact considering the proximity effects and the earthing arrangement in order to zero the touch-voltages in case of phase-to-enclosure short-circuit. The chief features of GIL solution are the lowest transmission power losses and the absence of shunt reactive compensation for this line length (appr. *65 km*) but mostly the safety of personnel in case of short-circuit and the possibility of usual re-closure cycles for operation continuity. This paper gives an overview of other analysis: GIL no-load regime, electromagnetic interferences between railway and GIL system, pilot tunnel ventilation and GIL thermal regime. In order to achieve satisfying power flows, the new link requires both Italian/Austrian regional grids (380 kV÷110 kV) to be restructured and rationalised. This research is supported by European Community in the framework of TEN-ENERGY programme for analysing both, technical and environmental issues of integrating 380 kV Gas Insulated transmission Line and Rail Transport in tunnel between Italy and Austria entitled "Studies for a new 380 kV transmission line between Italy and Austria through the Brenner pass: Integration of Electricity and Rail Transport in Tunnel". The project leader is TERNA (**Italian TSO**) whereas the associated beneficiaries are the University of Padova and TIWAG-Netz AG (**Tyrol TSO**) with support of Graz University of Technology.

KEYWORDS

Gas Insulated Lines (GIL), No-load Regimes, Electromagnetic Interference, Multiconductor Matrix Algorithm, Transnational Networks, EHV Transmission Lines, Tunnel Ventilation.

♦♦markus.laussegger@tiwag-netz.at

SHARED STRUCTURES: RAILWAY TRANSPORT AND POWER TRANSMISSION

In the balance of Italian electric grid, the import energy weights sensibly upon the total demand. Fig. 1 shows a meaningful sketch of the import energy (wholly *46* TWh) in 2004 which is the *14,3* % of the total demand (*322* TWh) and in particular highlights that the power exchanges between Italy and Austria are today the smallest.

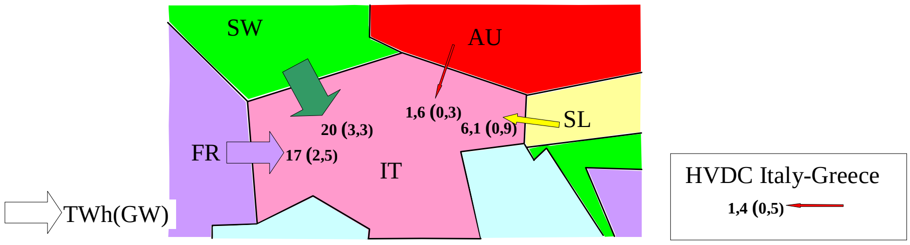


Fig. 1. Electric energy (power) exchanges at Italian border in 2004

This is due to the limited capability of the *220* kV OHL link *Soverzene(IT)-Lienz(AT)*. Therefore, a cross-border link at 380 *kV* between Italy and Austria is absolutely necessary.
In this context, the new planned railway galleries between Italy and Austria under the Brenner Pass represent besides an important step towards the lightening of the transports via highway also an unique opportunity for considerable power exchanges [1] by means of the installation of double-circuit GIL in the "pilot tunnel". Fig. 2-a shows the future route of the galleries between Fortezza (Italy) and Innsbruck (Austria) with length of about *65 km*. Two separate tunnels (see fig. 2-b) will constitute the railway galleries (one for each railway track) and a pilot tunnel will precede them in order to assess the geologic situation of the rock stratigraphy, to drain water away and to convey the mucking during the main gallery construction. Once the whole work will be over, the pilot tunnel (*4,3 m* diameter) will be used as a service gallery where a double-circuit GIL can be suitably installed (see fig. 2-c). The direct installation of a single-circuit GIL (*2,0 m* × *0,7 m* in size) inside each proper railway gallery would require a more expensive installation. The introduction of GIL elements (length *12-15 m* or longer) can be made also through the intermediate accesses in correspondence of MFS (Multifunction Station), which are distributed along the pilot tunnel so to shorten the transport on service trolley.

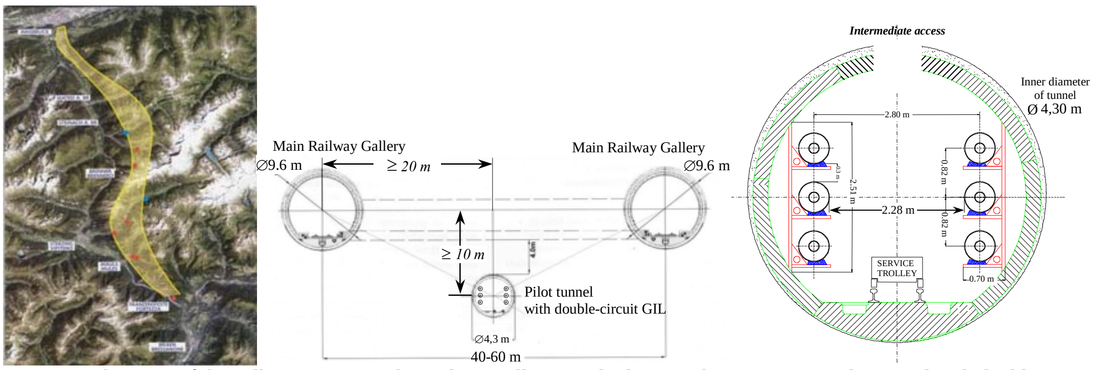


Fig. 2. a) The route of the galleries; b) Railway galleries and pilot tunnel; c) Pilot tunnel with double-circuit GIL

GIL PARAMETERS AND INTERCONNECTION PERFORMANCE

For GIL characteristics and analysis, a number of papers (e.g. [2]) have already been published. The geometrical characteristics foreseen in this paper are reported in tab. 1-a. Among the data in tab. 1-b the lowest value (~ *2,3 mΩ/km*) of enclosure resistance r_{en} is a key factor: the study, carried out on the multiconductor system of single and double-circuit GIL (*50 Hz*), modelled by means of Carson's theory and analysed with advanced matrix algorithms [2, 3, 4], shows that the skin effects (with phase and enclosure thicknesses of *10 mm*) and proximity effects are negligible and that the lowest value of r_{en} allows (with solid-bonding connection) the induced current in each enclosure to be almost equal in magnitude and opposite in angle to the corresponding phase current, so that a very good approximation consists in the study of GIL as a symmetric three-phase line with decoupled phase conductors having an equivalent resistance equal to $r = r_{ph}+r_{en}$. Hence, the transmission parameters are reported in tab. 1-c and the double-circuit *65* km performance in tab. 2.

TABLE 1 DATA OF 400 kV GIL

a			**b**				**c**			*f=50 Hz*
*Phase cross-section (Al IACS=61%)**	**mm^2**	*5341*	*d.c. resistance of phase at 60° C*	r_{ph}	**mΩ/km**	*6.286*	*Longitudinal impedance*	$\underline{z}=r_{ph}+r_{en}+j\omega\ell$	**mΩ/km**	*8,6+j64*
*Enclosure cross section (Al alloy IACS=52.57 %)**	**mm^2**	*16022*	*d.c. resistance of enclosure at 50°C*	r_{en}	**mΩ/km**	*2.330*	*Shunt admittance*	$\underline{y}=g+j\omega c$	**mS/km**	*0+j 0,017*
Phase Outer Diameter	**mm**	*180*	*Phase-enclosure voltage*		**kV**	$400\,kV/\sqrt{3}$	*Characteristic Impedance*	$\underline{Z}_0=\sqrt{\frac{\underline{z}}{\underline{y}}}$	**Ω**	*61.46 ∠-0.07 rad*
Enclosure Inner Diameter	**mm**	*500*	*Phase-enclosure inductance*	ℓ	**mH/km**	*0.204*	*Propagation Constant*	$\underline{k}=\sqrt{\underline{z}\cdot\underline{y}}$ $\underline{k}=k'+jk''$	**1/km**	*0.0001 + j 0.001*
Phase and enclosure thickness	**mm**	*10*	*Phase-enclosure leakance*	g	**nS/km**	*negligible*	*Surge Impedance Loading at 400kV*	$SIL=\frac{400^2}{\lvert\underline{Z}_0\rvert}$	**MVA**	*2604*
Insulating gas SF_6/N_2	**%**	*20/80*	*Phase-enclosure capacitance*	c	**μF/km**	*0.0545*	*Capacitive current related to U_o= $400\,kV/\sqrt{3}$*	I_{cap}	**A/km**	*3.95*
Pressure	**bar**	*7*								

*IACS = International Annealed Copper Standard (IACS=100 % ⇒ Copper Standard Conductivity = 58,108 m/Ω·mm²)

TABLE 2 PERFORMANCE OF DOUBLE-CIRCUIT GIL, L=65 km

U_R=400 kV (at receiving-end)					
$\underline{S}_S$ [MW] +j [Mvar]	$\lvert\underline{S}_R\rvert$ [MVA]	$\underline{S}_R$ ($\cos\varphi=0.98$) [MW] +j [Mvar]	$\lvert\underline{U}_S\rvert$ [kV]	ΔP average [W/m]	ΔU [%]
0,07 - j 354,73	*0*	*0*	*399,1*	*1.1*	*-0,23*
981,7 – j 145,19	*1000*	*980 + j 199*	*400,8*	*26*	*0,20*
1966,8 + j 90,35	*2000*	*1960 + j 398*	*402,6*	*105*	*0,65*
2955,4 + j 351,89	*3000*	*2940 + j 597*	*404,5*	*238*	*1,13*
3947,6 + j 639,42	*4000*	*3920 +j 796*	*406,5*	*424*	*1,63*

From tab. 2, it may be observed that:

- In spite of the high power flows, voltage drops are very low and average overall active losses are fully satisfactory and noteworthy in global cost evaluation;
- In a wide load range GIL gives an effective power factor correction at sending-end;
- For this link length, the capacitive power at no-load appears acceptable.

For continuous regimes (e.g. S_R=*2000 MVA* of tab.2, *I=1,44 kA*) which give rise to overall power losses equal to 105 W/m, ventilation arrangements are foreseen in the pilot-tunnel in order to guarantee an ambient temperature of *40° C* and an enclosure maximum temperature of *70° C*. Heavier regimes (e.g. *3000 MVA*, with more than double power losses) can be considered as emergency operations with a more forced cooling.
The last row of tab. 2 with very high power exchange (e.g. *4000 MVA*) can be considered meaningful only in overload conditions.
Moreover, the capability chart in fig. 3 (derived from the procedures in [5]), gives a comprehensive synopsis of all the other performances compatible with the ampacity I_a = *1,44 kA* (for a single-circuit GIL of *65 km*) and confirms the high efficiency of the proposed GIL link.

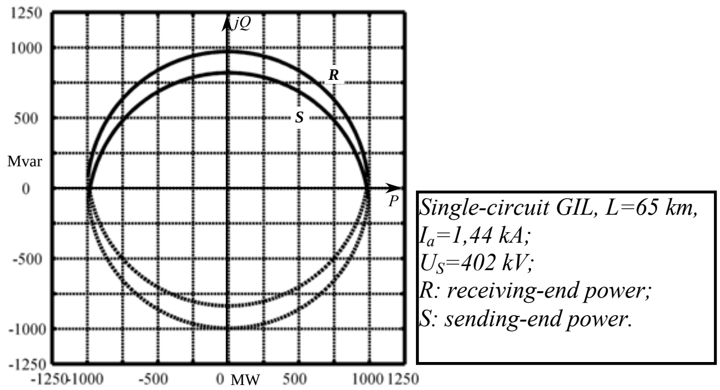


Fig. 3. Power Capability Chart for single-circuit GIL

NO-LOAD REGIMES

It is immediate to calculate that the double-circuit GIL (*L=65 km*), supposed as lossless line supplied at $U_s = 400\ kV$, absorbs at no-load regime (to foresee both as an accidental and as a normal situations) the capacitive power $Q_C = 2 \cdot \frac{400^2}{Z_0} \cdot tg\,k''L \cong 360\ Mvar$; this occurrence will not have to be neglected in the power flow studies, which will help the TSOs to choose the suitable power system configurations in the surrounding areas of the interconnection ends.
For a first approximated but meaningful approach devoted to highlight the limit lengths due to no-load regimes, the supply can be modelled as an equivalent generator (as seen at node *S*): it is characterized by its electromotive force (which is supposed to be $U_o^* = 230\ kV$) and the short-circuit impedance (for simplicity purely inductive jX_{sc}); the no-load regime at *R,* deriving from the insertion of a single-circuit GIL at *S*, is completely defined by

$$\underline{U}_{oS} = \frac{U_o^*}{jX_{sc} - jX_C} \cdot \left(-jX_C\right) \quad , \quad \underline{U}_{oR} = \frac{\underline{U}_{oS}}{A_{id}} , \tag{1}$$

where $-jX_C = A_{id} / \underline{C}_{id}$ (A_{id}, $\underline{C}_{id}$ are the classical transmission parameters) is the capacitive impedance of a lossless (ideal) single-circuit GIL. With regard to X_{sc} evaluation, it is possible to refer firstly to the subtransient impedance U_o^* / I''_{sc}; the values of subtransient current I''_{sc} (three-phase at *S*) are foreseen in the range $10 \div 30\ kA$, so that X_{sc} corresponds to $23 \div 7{,}6\ \Omega$.
Due to the capacitive nature of load $-jX_C$ at *S* and the Ferranti's effect at *R*, $|\underline{U}_{oR}| > |\underline{U}_{oS}| > U_o^*$ will be always verified, so that in any case the phasor $\underline{U}_{oR}$, computed by means of (1), must not exceed the magnitude $242.5\ kV = U_m/\sqrt{3}$ ($U_m = 420\ kV$). The length at which this happens is the maximum allowable no-load length L_e. Fig. 4 shows L_e for single and double-circuit GIL as a function of short-circuit reactance: when the network is strong, the limit length is rather high both for single-circuit and double-circuit whereas when the network is weak (namely with three-phase short-circuit currents up to *10* kA) the limit length reduces considerably. These first meaningful considerations on the subtransient regimes must be followed by an in-depth analysis on the power flows to assess the no-load steady-state regimes.

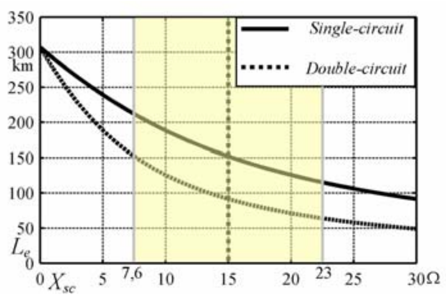


Fig. 4 No-load limit lengths L_e versus short-circuit subtransient reactance X_{sc} ; ($U_o^* = 230\ kV$)

MULTICONDUCTOR SYSTEM ANALYSIS

The validity of simplified positive sequence modelling yielding the results of tab. 2 can be also confirmed by the throughout and in-depth multiconductor analysis which gives the possibility to highlight precisely a lot of other effects.
In this paper, the description of the theoretical procedures cannot be particularly detailed.

Elementary cell and Line matrix

The study of multiconductor system constituted of polyphase lines, where each conductor runs parallel to the others and to the ground surface, must primarily characterize the longitudinal parameters of self and mutual inductive and resistive couplings, by means of classical theory developed by Carson (well presented and widely used in [6]) and of the shunt conductive and capacitive couplings; successively it is possible to form the elementary cell matrix $\boldsymbol{Y_C}$, with sufficiently short length Δ (e.g. *250* m) and, with suitable matrix algorithm [7], to achieve the line matrix $\boldsymbol{Y_L}$ as an equivalent of a cascade of *n* cells. If the target is an accurate analysis of the voltage and current distribution in individual cells along the line, it is useful alternatively an extended block-diagonal matrix representation as in [2].
It is worth noting that in the case of Brenner tunnel where the electric system runs at great depth in the rock, the Carson's theory can be still used if the "rock coverage" (with a given average thickness of *850 m* above tunnel) is modelled with cylindrical conductor layers of resistivity equal to the rock type; but it can be ascertained that owing to the high average resistivity ($3 \div 10\ k\Omega\, m$) the rock coverage can be neglected. Therefore, the interconnection system requires a 13 elements cell modelling (*6* phases, *6* enclosures and 1 metallic grid embedded in the pilot-tunnel): fig. 5 also shows the end substation modelling, including the parallel constraints (between sections S_0 and S_1; between S_n and S_{01}). Other constraints (regarding supply cyclic order and non-parallel operation) can also be considered.
A great number of simulations have been carried out on this modelling and have demonstrated that the not-perfectly symmetric structure determines regimes along the system with smallest unbalance degrees ($1 \div 3$ ‰) even if imposing symmetric voltages *R, S, T*, at both ends.

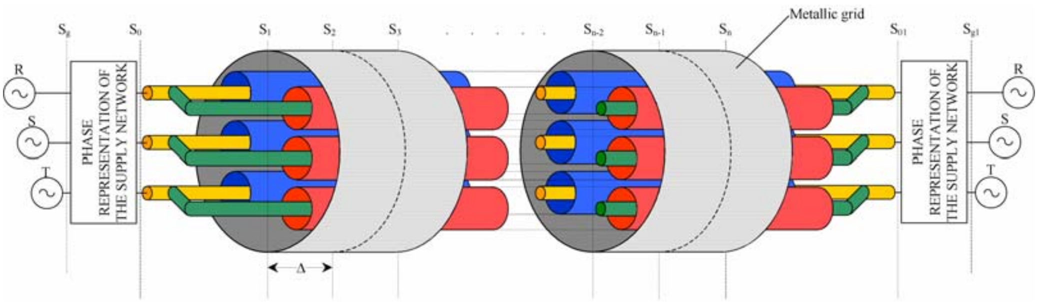


Fig. 5. Representation of double-circuit GIL installed in pilot tunnel with receiving and sending end substations

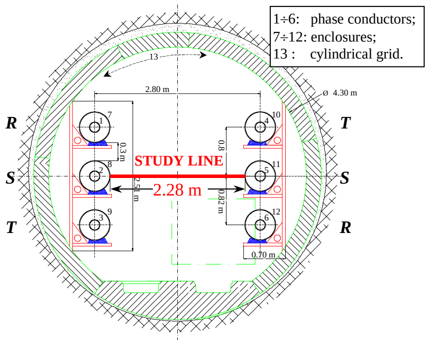
Proximity effects

Some co-authors have already developed a matrix integral algorithm to study the proximity effects of single-circuit GIL [3]: the generalization to the double-circuit GIL is detailed in [4].
Therefore, it has been evaluated that in the usual installations the proximity effects are not so marked even if the conductors (chiefly the not filiform enclosures) are very close.
The method is based on an extensive application of matrix analysis of multiconductor systems: each phase and enclosure can be divided into a bundled equivalent conductor of *m* sub-conductors, whose self and mutual longitudinal impedances can be computed applying the Carson theory.
A comparison with Finite Element method has been performed giving a good agreement: the procedure allows calculating in an easier way the additional power losses due to proximity effects which result always bearable even with small enclosure spacing. In any case, an enclosure minimum spacing of *0.3 m* is advisable for orbital welding use.

Magnetic impact

GIL installation allows a very effective magnetic shielding, due to the enclosure current phasors, which, as stated above, have almost the same magnitude and are almost opposite to corresponding phase current phasors: it ensures a high electromagnetic compatibility with other neighbouring systems inside the tunnel. A precise study [8] of magnetic fields generated by GIL has been computed in order to evaluate the magnetic levels inside and outside the tunnel. The most meaningful results are summarised as follows:

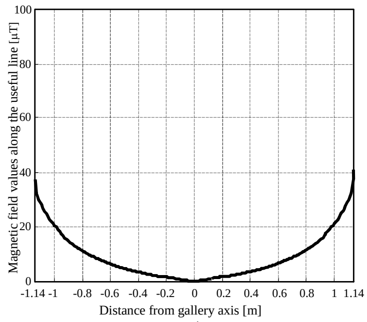
- the supply configuration that minimizes the magnetic field is the antisymmetric one (*RST-TSR* as in fig. 6a);
- the sum of phase current phasor and that of enclosure current is always very small (fig. 6 b) so that the external magnetic fields are negligible;
- the magnetic field value close to the enclosures does not exceed *40* μT (see fig. 6c for *2000 MVA*) but at the distance of *3 m* from gallery axis it is below *3* μT ;
- the value of *100* μT is never exceeded, inside the tunnel, neither in overload operation (*4000 MVA*).



a)

Receiving-end Currents [A]				
Phases			Enclosures	
R	1	|1442| ∠-4°	7	|1423.4| ∠169°
S	2	|1442| ∠-124°	8	|1441.7| ∠49°
T	3	|1442| ∠116°	9	|1460.1| ∠-71°
T	4	|1442| ∠116°	10	|1460.1| ∠-71°
S	5	|1442| ∠-124°	11	|1441.7| ∠49°
R	6	|1442| ∠-4°	12	|1423.4| ∠169°
Cylindrical grid			13	| 37.3| ∠144°

b)



c)

Fig. 6 a) Multiconductor system; b) Current phasors at receiving-end; c) Magnetic field values inside the pilot tunnel

Phase-to-enclosure short-circuit

A phase-to-enclosure short-circuit can be accurately studied by completing the modeling in fig. 5 and connecting a high conductance link between phase and enclosure and by adding in the system admittance matrix the subsequent conductance fault matrix [9].
It has been verified that the small values of *GIL* impedances affect very slightly the short circuit current, which depends chiefly upon the equivalent impedances of the two terminal substations: it is foreseen a subtransient phase-enclosure fault current of about *25 kA*.
Moreover, a very effective arrangement for operators safety can be obtained if the enclosures and the metallic grid (see *13* in fig. 6a) are systematically bonded together at short intervals so to practically zero the touch voltages also in the faulty section (as confirmed by multiconductor calculations).
Another fundamental feature for the personnel security and for operation continuity is the GIL withstand to the arc effects: GIL manufacturers have to guarantee a rated short time withstand current according to IEC 61640 [10] (usually *50 kA* for *3 sec*).
It should be noted that GIL insulating medium is self-repairing after a disruptive discharge so that the re-closure cycles usually adopted for overhead lines can be operated as well.
It is of note that he electrodynamic forces are self-centring inside the enclosure and extremely low outside.

The installation is usually equipped with electronic monitoring and diagnostic systems: fault location equipment can be also installed at both ends of GIL with an accuracy of about *± 10 m*.

THERMAL BEHAVIOUR OF THE TUNNEL AND VENTILATION REQUIREMENTS

Since the active power losses may likely be about *7 MW* (see tab. 2), the thermal behaviour of BBT pilot tunnel and its ventilation requirements have been evaluated by resorting to a suitable computer model. This model is based on a "control volume" approach: a discretization of the space and time domains leads to a network of thermal capacities and resistances to be solved time after time by means of a linear algebraic system.

Simulations are referred to the pilot tunnel, with an inner diameter of *4.3 m*, surrounded by a concrete vault *0.35 m* thick and by a rock layer with *400 m* outer radius. The choice of this radius came from preliminary assessments of the distance where the effects of the power line are negligible for the whole operational life of the installation. The thermo-physical properties of materials and rocks have been obtained from [11]; the same reference also provided the initial rock temperature (which are quite high, up to *41 °C*) and the outdoor air temperatures for the Alpine area.

The internal heat production during the operation of the power line has been assumed to be constantly equal to *120 W/m* (with a conservative margin of *15 %* with respect to tab. 2) for the whole set of double-circuit and, in order to control overheating inside the tunnel, different ventilation strategies have been assessed.

For some of them, the resulting air temperatures along the tunnel at different times of operation (*1, 3, 10, 50* and *100* years) are shown in fig. 7 and fig. 8: the benefits which can be obtained by increasing the ventilation rate and by using intermediate shafts (located in the three *MFS sites*) can be easily assessed. The enclosure temperature of *70 °C* is never exceeded.

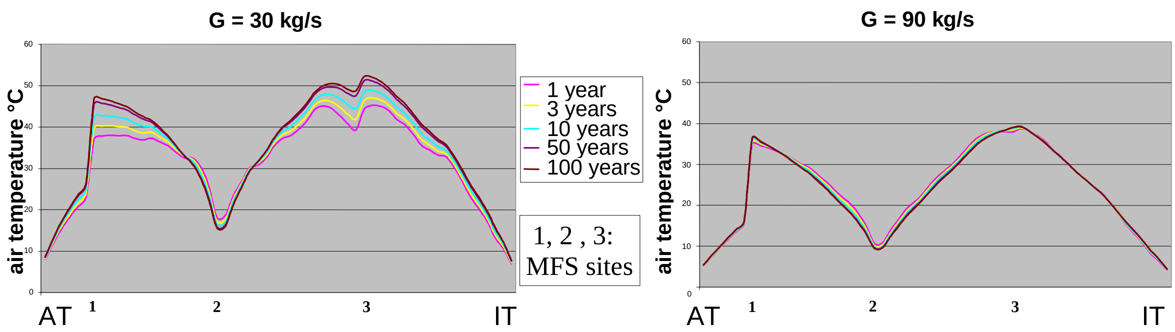


Fig. 7 Air temperature along the tunnel at different times of operation, with air flow-rate G=30 kg/s and G=90 kg/s; inlets at the Italian entrance (IT), MFS 2 and Austrian entrance (AT), outlets at MFS 1 and MFS 3

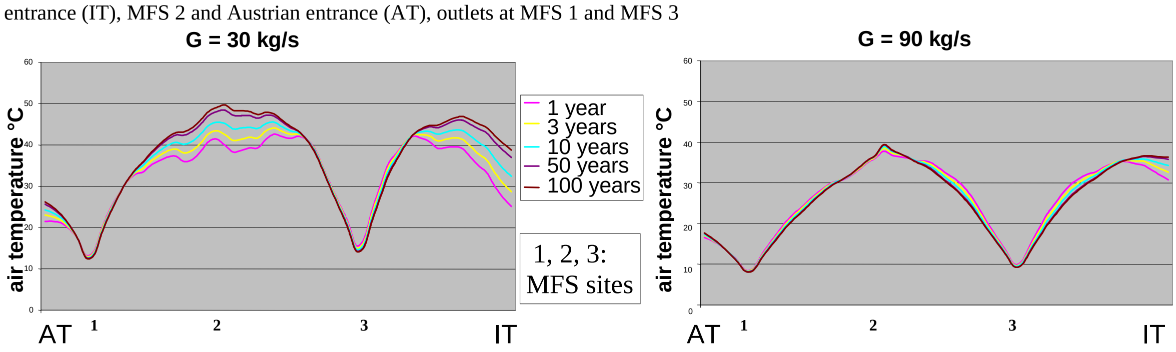


Fig. 8 Air temperature along the tunnel at different times of operation with air flow-rate G=30 kg/s and G=90 kg/s; inlets at MFS 1 and MFS 3, outlets at Italian entrance (IT), MFS 2 and Austrian entrance (AT)

The resulting air velocity may be incompatible with the presence of personnel for maintenance inside the tunnel but the fans will be easily shut off during maintenance work.

All previous simulations refer to dry air flowing through the tunnel, though water infiltrations will likely occur and the consequent "evaporative cooling" should have positive effects on overheating control; this conservative approach has been adopted for the lack of data on the actual amount of water infiltrations during the operation of the tunnel.
Water phase change causes a smoothing effect of the temperature profile. Nevertheless, it has to be considered that a misplacement of this cooling mechanism might cause an increase of the relative humidity.

ELECTROMAGNETIC INTERFERENCE FROM RAILWAY SYSTEM

The long parallelism of railway and GIL system requires the assessment of electromagnetic interferences between themselves or other longitudinal conductors (e.g. metallic pipes, low voltage conductors etc). With regard to possible interferences due to GIL, the conclusions of the two Sections "magnetic impact" and "phase-to-enclosure short-circuit" highlights how the efficient shielding generated by the enclosures can avoid any effects. With regard to railway system, the planning of high-speed supply system has not been definitively decided: there could be a part at *2x25 kV* (*50 Hz*) and a part at *15 kV* (*16 ⅔ Hz*). The exact knowledge of the railway configuration and its supply system would allow a precise determination of regimes and possible interferences as in [12] for *2x25 kV, 50 Hz*. However, in absence of detailed data, preliminary results can be derived by hypothesising three conductors: *k* on the railway gallery axis with a current $I_k=1000\ A$ and ground return over indefinite length; *v* on the pilot tunnel axis at *23 m* far from *k*; *s* the cylindrical metallic grid for equipotentiality of structure but also for shielding purpose. By means of well-known formulae [6], it is possible to compute the shielding effect of *s* on *v.*
Tab. 3 gives the voltage magnitudes [*V/km*] induced on the conductor *v* (victim) versus the longitudinal resistance R_{sh} of the shielding grid *s* and shows how $R_{sh} \leq 0,1\ \Omega/km$ (not particularly expensive) gives satisfying shielding effects.

TABLE 3 INDUCED VOLTAGE MAGNITUDES ON VICTIM CONDUCTOR *v* ($\rho_{ROCK}=10000\ \Omega m$; *f=50 Hz and 16 ⅔ Hz*)

R_{sh} [Ω/km]	*0,01*	*0,1*	*1*	*10*	*100*
U_{v50Hz} [V/km]	***7,2***	***69,7***	***324***	***378***	***380***
$U_{v16,67Hz}$ [V/km]	***7,3***	***62,9***	***134***	***138***	***138***

It is worth noting that both the inducing current $I_k=1000\ A$ flowing over an indefinite length and the high rock resistivity equal to *10000 Ω* m are very conservative hypotheses.

OTHER TRANSMISSION TECHNOLOGIES

In the aforementioned EC TEN-Energy overall feasibility study, great attention has been paid also to the possibility of using a XLPE-cable link for power transmission through the Brenner Pass tunnel.
Both technologies have several advantages and disadvantages (see *tab. 4*), whereby especially the high possible transmission rate is a feature favouring GIL.
Other reasons for choosing a GIL in this especial installation are the lower magnetic impact due to the effective shielding of enclosures, lowest losses, null fire load, safety of personnel (in case of internal arc) and a less problematic cooling arrangement. The higher GIL investment costs have been also considered.
In same EC study, the on-site dielectric testing of installation (according to *IEC 62271-203*) has also been assessed: the possibility of sharing the long link into sections (of suitable lengths) will facilitate not only the on-site first dielectric tests but also those tests after repair or maintenance (see *Section 7.8.1.2* of *IEC 61640*).
The gas-tightness of the enclosure section along the whole GIL has to be guaranteed.
In general both GIL and XLPE-cable are suitable for the power transmission in a tunnel from a technical standpoint, although there are still no realized projects of this order of magnitude.

However, in order to guarantee an economically reasonable operation of the transmission system, taking into account all technical pros and cons which characterize the transmission technologies, the definition of the desired load capacity of the transmission line is one of the fundamental decision criterions.

TABLE 4 COMPARISON OF THE ADVANTAGES AND DISADVANTAGES OF THE TWO TECHNOLOGIES

	Advantages	Disadvantages
GIL	• *High transmission rate* • *Low Joule losses* • *Null dielectric losses* • *Re-closure cycles like overhead line* • *Low magnetic fields* • *Operation temperature: less problematic cooling* • *Null fire load* • *No danger of persons due to internal arc* • *No need of reactive shunt compensation* • *Good overload capability*	• *Larger external diameter of pipe, therefore wider route path* • *Higher investment cost* • *Less long time experience* • *High monitoring expenditures* • *Sensible against seismic activities* • *Possibility of leakage of greenhouse effect gas* • *Necessity of compensation devices for the thermal axial expansion*
XLPE-cable	• *Less expensive investment cost* • *Lower monitoring expenditures* • *No leakage of greenhouse effect gas*	• *Higher magnetic fields* • *Endangering of the XLPE-insulation at high temperatures* • *Noteworthy fire load in case of failure* • *Necessity of reactive shunt compensation* • *Danger of persons due to internal arc* • *New individual cable length after short circuit*

CONCLUSIONS

A meaningful example of integration of railway transport and electric transmission can be realized with the installation of a GIL system in the pilot tunnel of future high-speed railway galleries foreseen under the Brenner Pass.
An upgrading and requalification of both railway traffic and energy exchange of transnational grids can be achieved in a very important and central European area.
The electric system (GIL double-circuit), which the paper is devoted to, offers a high power performance and most of all guarantees both safety for personnel and continuity of operation by means of re-closure cycles, determinative factors in the comparison.
The investment cost of a double-circuit GIL is about 0,*26÷0,325 G€*.
Considering an estimated cost for the galleries of about *5,0 G€*, the cost ratio ***GIL/GALLERY*** would be about *5,2÷6,5 %*.
This percentage does not seem to be a heavy adding on the overall cost and is promising in view of a rationalisation of the corridors.
The importance of the project is confirmed by the support given by European Community to the feasibility study of 380 kV reinforcement of Italy-Austria interconnection for the development of European Energy Market [13].

BIBLIOGRAPHY

[1] R. Benato, E. M. Carlini, C. Di Mario, L. Fellin, A. Paolucci, R. Turri: Gas Insulated Transmission Lines in Railway Galleries (*IEEE Trans. on Power Delivery*. Vol. 20, Issue 2, April 2005).

[2] R. Benato, L. Fellin, D. Marzenta, A. Paolucci: Gas–insulated transmission lines: excellent performance and low environmental impact, (*Proceedings of International Symposium and Exhibition on Electric Power Engineering at the Beginning of the Third Millennium – EPETM,* May 12–18 2000, Napoli–Capri, Vol. 1, pp. 385–405).

[3] R. Benato, F. Dughiero, M. Forzan, A. Paolucci: Proximity Effect and Magnetic Field Calculation in GIL and in Isolated Phase Bus Ducts, (*IEEE Transactions on Magnetics*, Vol. 38, No 2, March 2002, pp. 781–784).

[4] R. Benato, F. Dughiero: Solution of Coupled Electromagnetic and Thermal Problems in Gas Insulated Transmission Lines, (*IEEE Transactions on Magnetics*, Vol. 39, No 3, May 2003, pp. 1741–1744).

[5] R. Benato, A. Paolucci: Operating Capability of Long AC EHV Transmission Cables, (*Electric Power Systems Research,* Vol. 75/1, July 2005, pp. 17-27).

[6] CCITT: Directives concerning the protection of telecommunication lines against harmful effects from electric power and electrified railway lines. Geneva, 1989.

[7] R. Benato, R. Caldon, A. Paolucci, Automatic Procedure for Electromagnetic Interferences between Electric Systems of Different Nature, (*Proceedings of Italian Electrical and Electronics Association (AEI) Annual Meeting*, vol. 3, 1997, Baveno, Italy, pp. 19-26 in Italian)

[8] R. Benato, L. Fellin: Magnetic Field Computation For Gas Insulated Lines Installed In Gallery, (*Proceedings of 39th Universities' Power Engineering Conference – UPEC 2004,* Bristol, UK, September 6-8, 2004; Vol. I, pp. 6-10).

[9] R. Benato, E. M. Carlini, C. Di Mario, L. Fellin, G. Knollseisen, M. Laußegger, M. Muhr, H. Wörle, R. Woschitz: (Gas Insulated Transmission Lines in Railway Galleries – Part II", *Proceedings of IEEE St. Petersburg Power Tech'05 Conference*, 27-30 June 2005, S. Petersburgh, Russia).

[10] IEC 61640, Technical report, first edition, 1998-07, Rigid high-voltage, gas-insulated transmission lines for rated voltage of 72.5 kV and above.

[11] BRENNER BASISTUNNEL: Eisenbahnachse München-Verona, Bericht 2002 (in German) – GALLERIA DI BASE DEL BRENNERO: Asse ferroviario Monaco-Verona, Rapporto 2002 (in Italian)".

[12] R. Benato, R. Caldon, A. Paolucci: Matrix algorithm for the analysis of high speed railway and its supply system. (*L'Energia Elettrica,* Vol. 75, No. 5, September-October 1998, pp. 304-311, in Italian).

[13] EC, 2003 2003/54/CE of the European Parliament and of the Council of 26 June 2003 concerning common rules for the internal market in electricity and repealing Directive 96/92/EC - Statements made with regard to decommissioning and waste management activities.