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THE NEW TURBIGO-RHO 380 kV TRANSMISSION LINE: AN EXAMPLE OF THE USE OF UNDERGROUND XLPE CABLES IN A MESHED TRANSMISSION GRID

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SUMMARY

The need of a 380 kV transmission line between the Power plant of Turbigo, near Milan, and the substations at Ospiate and Bovisio was highlighted from several years ago, with the primary scope to avoid congestions consequent to the high power transiting in the area and to reinforce the West-East transmission axis in the North of Italy.

Other benefits of this interconnection are the reduction of the overall transmission losses, the increase of power availability during summer and winter peak loads and in terms of better flexibility of operation.

The project construction started at end of March 2005 and will be in service in Spring 2006.

Due to the necessity to cross a highly urbanized area and to fulfil the stringent requirements in terms of environmental impact (electric and magnetic field limitation, visual impact, etc.) an underground XLPE cable system was decided to be installed throughout the whole sensitive area.

The present paper describes in detail the Underground XLPE Cable system, which represents the first realization of this extension and importance in Italy and also one of the most important world-wide.

The paper also describes an innovative solution adopted to minimize the Electromagnetic Field (EMF) when the cable systems are laid in the most sensitive areas; in this case the cables are installed in a trefoil configuration inside single plastic ducts and an effective EMF shield is provided all around the cables, constituted by a trough made of a special high magnetic permeability material.

In order to increase safety of operation, special controls have been foreseen for the whole cable system, in particular the continuous monitoring of the temperature through fibre optics and the possibility to measure the partial discharges during the system life.

KEYWORDS

Meshed lines, XLPE cables, Undergrounding, EMF shielding, PD monitoring, TERNA, Prysmian.

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1. THE NEED OF THE INTERCONNECTION

The need of a 380 kV transmission line between the Power plant of Turbigo, near Milan, and the substations at Ospiate and Bovisio was highlighted since the ‘90s. The absolute importance of the project was then confirmed by GRTN (now merged with TERNA), who included it in the National Development Plan in 2001 as a top priority project, key to guarantee the required reliability and availability to the transmission network.

The expected advantages from the interconnection mainly consist of:

- Overcoming of generation limits in the Lombardy region that are presently caused by transmission power limits in the local national transmission network
- Increasing the flexibility of the transmission system
- Reduction of transmission losses with consequent advantages from environmental and economical point of view
- Avoiding congestions consequent to the high power transiting in the area, partly due to the power imported from Swiss and France, thus increasing the power availability to better cover consumption needs
- Reinforcing the West-East transmission axis in the North of Italy

2. A DIFFICULT ROUTE

The new power connection runs for about 28 km in total, in the west suburbs of Milan, across a highly populated area and where environmental important parks and protected areas are present.
Main design criteria adopted for choice of the route for the overhead line is to avoid or to minimize the crossings of protected areas (environmental constraints, landscape issues, etc.), urbanized areas (even where residential buildings are planned for the near future), and those zones presenting soil instabilities (flooding mud, erosion, overflowing).
A further critical issue that had to be considered was the limit imposed to EMF by the Italian law: 5 kV/m for electric fields and 3 microT for magnetic fields at sensible receivers (i.e. where people live or work).
Considering all the mentioned restrictions the ambient conditions of the suburbs nearby Milan, finding a suitable corridor for a 380kV class overhead line was quite difficult.

3. THE APPROVAL PROCESS

The approval process for the realization of an overhead transmission line was started by ENEL in 1994. In 1996 the confirmation of the environmental compatibility was obtained, subject to few modification of the proposed design. However, in year 2000 the approval process was definitely stopped due to the opposition of the local communities involved.
In consideration to the strategic importance of the interconnection, TERNA evaluated alternative solutions, including possibility of undergrounding part of the interconnection.

Consequently, in 2003 the project was reviewed with the following modifications:

- Proposing use of underground cables in the most urbanized area, between Pogliano Milanese and Rho
- Modifying route and proposing new design solution for the overhead portion of the line, to overcome previous opposition from the local communities involved.

The fact that the realization was included in the strategically important items related to the national transmission network had permitted to adopt a simplified authorization process, according to the Italian legislation that was in the meantime issued (known as “Legge Obiettivo”).

Following the presentation to the Authorities of the revised project, including a new Environmental Impact Assessment, mainly relevant to the variations proposed as above described, the obstacles to the realization of the projects and the opposition from the local communities were overcome.
The final approval was obtained in September 2004; the final decision was supported by the proposal of financing a socio-economical and environmental plan in the area.

4. THE ADOPTED SOLUTION

4.1 Meshed line

The final solution for the new 380 kV connection "Turbigo - (Rho) - Bovisio" is a meshed system, including overhead lines and underground cables, as follows:

- A 20 km long segment of single-line overhead between Turbigo Power Station and the town called Pogliano Milanese, replacing the existing 220 kV connection "Turbigo - Ospiate", which will be dismantled;
- A transition compound between OHL and underground cables, in Pogliano Milanese;
- A cable section 8,4 km long between Pogliano Milanese and Rho, consisting on two three-phase circuits in parallel;
- A transition compound between underground cables and OHL, in Rho;
- Use of an existing 380 kV OHL which is linking Rho and Bovisio (currently a double-line 380kV overhead is in operation, connecting Baggio and Bovisio, forming the links "Baggio - Bovisio" and "Baggio - Ospiate - Bovisio").

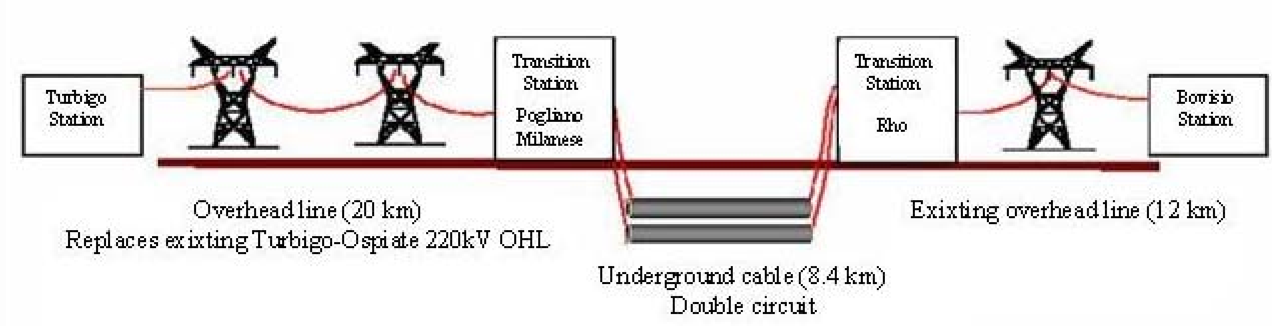

Fig. 4.1 – The principle scheme of the new 380kV meshed line

One of the main goals during the design stage has been to maximize the power carrying capacity of the entire connection. For the Overhead Line, the reference standard in this case has been the three-wire conductor (31.5 mm diameter, 585 mm^2 cross section) widely used in Italy for the 380 kV network..

The thermal ratings in accordance with IEC Standards and Italian CEI 11-60 are calculated with probabilistic method as follows:

	Summer	Winter
Normal operation condition	2040 A	2310 A
Temporary overload 1‰	2770 A	3140 A

The maximum currents considering a maximum conductor temperature of 75 °C and wind speed of 2 km/h are calculated with deterministic method as follows:

	Summer (30 °C)	Winter (10 °C)
Normal operation condition	3400 A	2740 A
Temporary overload 1‰	3290 A	4080 A

For the underground cable section, the choice has been to avoid having, in any possible operating condition, a bottleneck for the complete system, both from power rating point of view and with respect to the operations related to the event of any damage or maintenance.
Another requirement has been to assure the highest level of reliability, also considering the protection systems currently in use for 380 kV systems. In particular the selectivity of the protection devices for rapid and slow re-closure cycles had to be maintained i.e. in case of non-transient faults (on cables) the line shall not be re-close whilst for faults on the OHL (generally transient events), the cycle has to be completed.

The adoption of the described meshed solution, including a 8,4 km long double circuit underground cable section, is possible also because the local power network is well interlocked and the short circuit power is sufficiently high to allow the cable section (a highly capacitive component for the system) not to introduce any possible disturbances and any consequent additional works for a reliable voltage control.

4.2 Circuit route

A scheme of the entire route is shown in Fig. 4.2.
The overhead section is about 20 km long with a single circuit on delta-type poles (in accordance with TERNA's standards).
The underground section between the transition stations is mainly running along roads owned by local authorities (Province of Milan, municipalities) with many crossings (roads, rivers, gas pipes, MV cables, railways, etc.).

Legend
380 kV OHL — Existing 380 kV OHL
380 kV XLPE cables — Borders of Municipalities
Transition stations between OHL and Underground Cables

Fig. 4.2 – 380kV meshed line "Turbigo-Rho": the route

5. TECHNICAL CHARACTERISTICS OF CABLE SYSTEM

5.1 Background

Cables with XLPE insulation are currently the standard solutions for all 132-150 and 220kV systems in Italy, whilst up to now the majority of 380kV cable connections in Italy and particularly within TERNA are using Self-Contained Fluid Filled cables (SCFF).
This traditional and long-experienced technology (SCFF) has been widely used for short connections within and between power stations and substations. Also the 380kV a.c. cable connection being part of the RTN (Rete di Trasmissione Nazionale, the Italian transmission network) which is the submarine link across Messina Strait, connecting Sicily with the Italian peninsula, consists of SCFF cables.

The development of 380kV cables with XLPE insulation has been followed with particular care from TERNA (and from ENEL in the past). Indeed in the ‘90s ENEL had an agreement with BEWAG to participate to the prequalification process undertaken by all main manufactures at CESI laboratories. Tests were initially based on Cigré publication Electra 141, then evolved in IEC 62067 Standards, but ENEL specified additional overload cycles to better simulate the needs of the Italian network.
Recently TERNA acquired direct practice about 380kV XLPE cables, installing five connections within Rondissone substation, near Turin. This has been the first experience for extruded cables at this voltage level in Italy.

Based on mentioned experience and since EHV XLPE cables are worldwide consolidated, TERNA decided to specify this technology for the new Turbigo-Rho connection.

5.2 The Technical Specification

The first aim of the Specification for the underground cable connection has been not to limit the performances of the entire link, which included OHL, both in terms of transmission capability and reliability.
As a result a wide set of technical requirements and tests were specified, the main of which are herewith described.

5.2.1 Prequalification

In line with the criteria mentioned before, it was required that the manufacturer performed prequalification tests on the complete system, including cable and accessories.
Such prequalification tests had to include:

- Long duration test with heating cycles, as per IEC 62067
- At least 15 overload cycles with conductor temperature of 103±3°C, to be performed during or just after the a/m long duration test
- Lightning impulse test on the complete system or on samples taken from the loop subject to a/m long duration test (10 positive and 10 negative impulses at 1425kV, as per IEC 62067 and IEC 60230).
- Power frequency withstand test at 2Uo during 15 min. on the objects subject to a/m lighting impulse test.

5.2.2 Type tests, factory tests, site tests.

TERNA Specification reflected IEC 62067 standards, thus considering the acceptance of type test reports covering the proposed cable in accordance with the “Range of type approval” specified in such Standard.
Factory tests i.e. Routine and Sample tests are the same as per IEC 62067, including the sampling frequency.
As far as electrical tests after installation test, IEC specifies a d.c. test of the oversheath and an a.c. test of the insulation. For this latter test, both soak test and test with resonant equipment are allowed. In order to ensure the safety of the network during the test, TERNA decided to specify the test to be performed at 260 kV during 1 hour (as per Table 10 of IEC 62067), by means of suitable resonant test sets.

5.2.3 Technical characteristics and performances.

The main driver for the choice of the system solution was the need to match the same maximum ratings (thermal limit) as per the OHL section.
Once excluded the force cooling for the entire system, deemed to be too complex for installation and operation, it was decided to have two three-phase connections in parallel.
This solution led also to a higher reliability for the entire link, especially in case of out-of-service of one of the connections.

Main requirements for the system were specified as listed in Table 5.1.

Circuit length	8400 m
Number of three phase connections	2
Type of cable	Single core XLPE
Nominal rated voltage Uo/U	220/380 kV
Maximum continuous rated voltage	420 kV
Lightning impulse withstand voltage	1425 kV
Switching impulse withstand voltage	1050 kV
Power frequency	50
Required maximum current at 380kV:	1600 A
Daily load factor	100 %
Single-phase short-circuit current	50 kA (0.5 sec.)

Table 5.1

Installation layout was also specified. Design parameters are listed in Table 5.2.

Cable laying	Directly Buried
Laying depth (to bottom of trench)	1500 mm
Cable laying arrangement	Flat
Distance between phases	350 mm
Distance between circuits	6 m
Sheath bonding	Cross Bonding

Table 5.2

In addition, it was required for the system to be provided with suitable monitoring systems, to be properly shielded against EMF, to include an optical cable for data transmission.

5.3 Adopted solutions

Based on above requirements and following a public Tender process, a turn-key contract has been awarded to Prysmian (Pirelli at time of contract signature).
Cable, accessories, auxiliary components are all state-of-the-art. They are designed and engineered to comply with the Specification and to provide a reliable system.
Cables are manufactured in the EHV plant in Gron (France); accessories are made in Livorno (Italy).

5.3.1Cable design

The proposed solution is a single core XLPE insulated cable (ref Fig. 5.1) designed for Um = 380 kV, maximum continuous operating voltage, and Up=1425 kV, lightning impulse withstand voltage.
The cable has a Milliken type copper conductor, with a cross section of 2000 mm2, longitudinally watertight by means of hygroscopic tapes.
Insulation consists of extruded cross-linked polyethylene (XLPE) suitable for operation at conductor temperature 90 °C, extruded simultaneously with the semi conductive conductor and core screen (triple head extrusion).
Under the metallic sheathing, a longitudinal water barrier is applied in order to limit the water penetration along the power core in case of cable damage.
The cable is provided with a Longitudinally Welded Aluminum Sheath, thick enough to withstand the rated Phase-to-Earth short circuit current. The metallic sheath acts also as a radial water barrier. The

Longitudinally Welded Aluminum Sheath is also considered to be reducing the overall impact on the environment, due to the material and the process applied.
The anti-corrosion protection consists of an extruded PE sheath. The cable outer sheath has an overall thin layer of graphite to permit the after laying voltage test of the sheath.

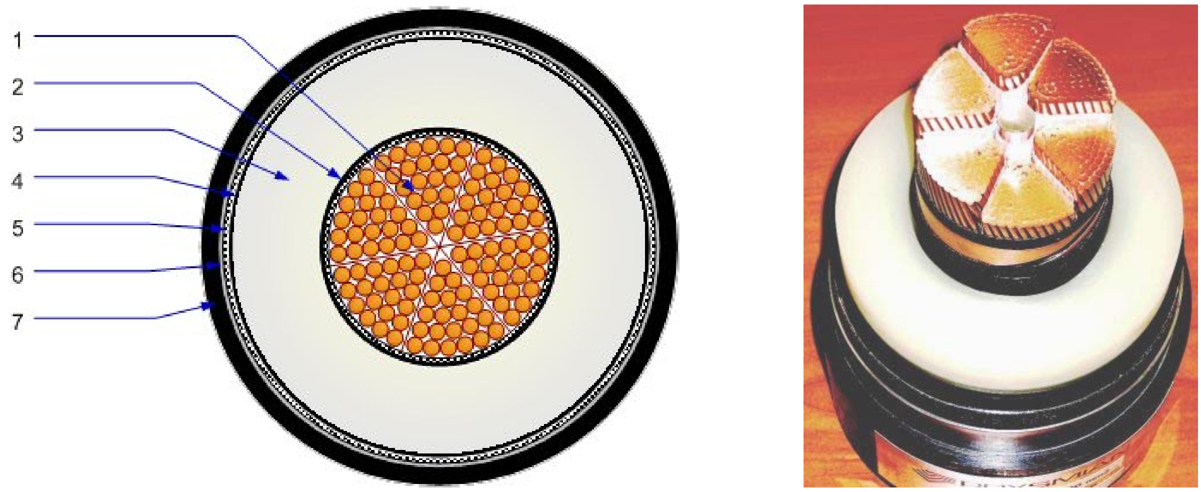

Fig. 5.1 – 380 kV cable, 1 x 2000 mm^2

1) CooperMilliken conductor, waterblocked; 2) semiconducting screen; 3) XLPE insulation; 4) semiconducting screen; 5) semiconducting waterswellable tapes; 6) Welded Aluminum Sheath; 7) PE outer sheath.

Cable has been design to comply with the required performances. Moreover, starting from 80% loading, it is capable to be overloaded at 180 % for 5 hours.

5.3.2 System design and accessories

The cable section of the Turbigo-Rho 380 kV line is a double circuit, approximately 8,4 km long.
Metallic sheaths of the cables are electrically connected in a cross bonding system.
Each phase consists of 12 cable spans, therefore having four major cross bonding sections of three cable segments each.
The minor sections are connected using sectionalized joints. At these points the cable sheaths are cross-bonded via suitable link boxes, provided with Surge Voltage Limiters (SVLs). Straight joints are used to connect the major sections. At these points the cable sheaths are solidly bonded and earthed through three-core disconnecting link boxes. At the terminations, the cable sheaths are connected to earth using disconnecting single-core link boxes.
Joints are of premoulded type, with the electrical part (insulation) consisting of a single piece sleeve.
All accessories are provided with a capacitive sensor in order to allow partial discharge monitoring.

5.3.3 EMF shielding

One of the most important constraints is the electromagnetic field produced by electrical lines. For the underground cable portion only the magnetic field is present.
Italian laws specify a maximum of 100 microT, with a threshold of 3 microT for those called “sensible receivers” (i.e. where human presence may last 4 hours per day).
Where EMF have to be limited within 3 microT, cables are installed in trefoil formation, enclosed in a raceway (see Fig. 5.2) made of special high magnetic permeability material.

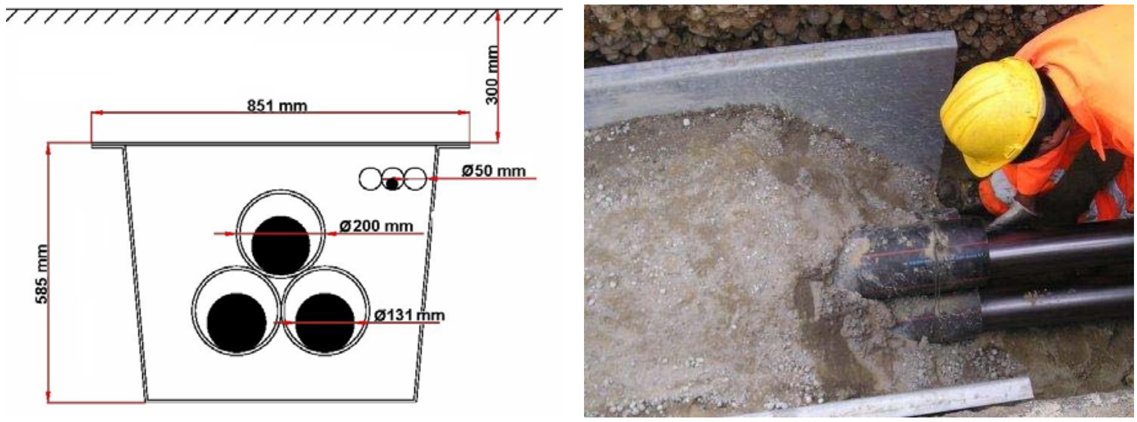

Fig. 5.2 – Raceway design and its installation

The ferromagnetic raceway is composed of different elements: the hull, the cover and the closing clips. The raceway is made of special steel, suitably protected against corrosion.
The design of the described open raceway system (specially developed and designed by Prysmian) combines the closed perimeter shielding efficiency with an open shape and the absence of welding.
The particular shape allows also the raceways to follow the curves of the trench and lateral and vertical variations of direction.
It is important to underline that the raceway design is an integral part of the system design and its dimensions are tailored for this project. Indeed they have to reach the optimum compromise between the EMF shielding effect and the minimization of the derating for the power cables.
With the Specified layout (flat formation, 350 mm cable axial distance, 6 m distance between circuits) and the cables fully loaded, the EMF curves with and without raceway are as shown in Fig. 5.3.

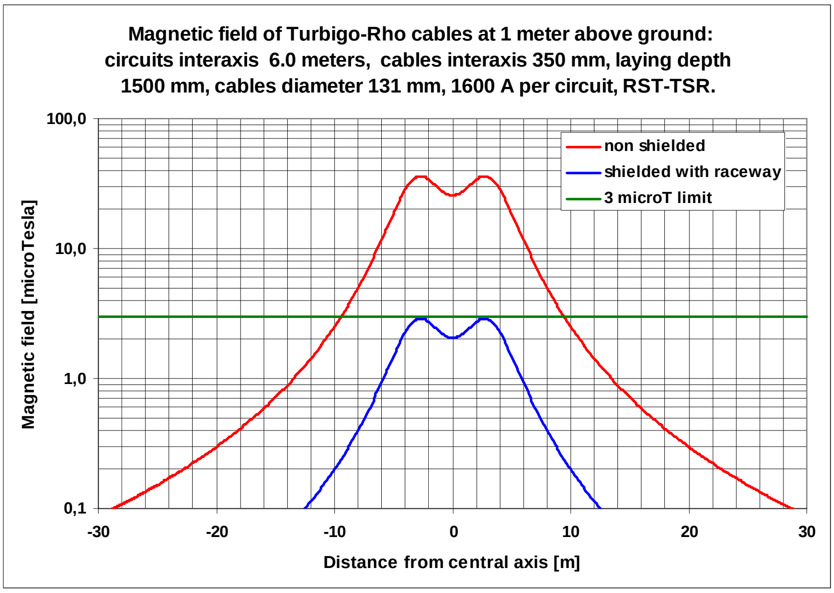

Fig. 5.3 – Magnetic fields

5.3.4 Monitoring systems

In order to continuously monitor the performances and the behavior of such an important connection, the system is provided with a variety of monitoring systems, e.g. a DTS system for thermal monitoring which collects all the information about the cables physical variables by means of suitable sensors (in this case, fiber optic cables laid on top of the hottest phase).
However, the most innovative of them is relevant to the permanent monitoring of partial discharges.

5.3.4.1 Partial Discharges permanent monitoring

Partial discharges (PD) activity in both circuits will be permanently monitored. All installed accessories have an embedded capacitive sensor and are permanently connected through special cable to the monitoring system.
Today there are no standards for PD measurement on-site, mainly due to external and background noise level that can be neither foreseen nor limited below a given threshold a priori.
For these circuits a PD detection system based on fuzzy logic has been chosen.
All accessories are connected to several local acquisition unit (three accessories, one per phase, to one local unit), and all the local unit are connected to an Ethernet LAN in S-ring configuration.
Such configuration allows continuity in PD monitoring activity even if one or more channel of one or more acquisition unit should experience any problem.
In the control room there will be a server connected to the mentioned LAN acting as interface towards the external words. This serve will allow remote monitoring and data analysis and the fully management of the monitoring system.
PD threshold will be set up and will pilot alarm as simplified human interface.

6. CABLE LINK INSTALLATION

The cables are installed in two separate trenches on the opposite sides of the roads and different installation solution are adopted for the different conditions encountered along the route as follow:

6.1 Adopted laying solutions

6.1.1 Main roads installation configuration

The cables are laid in flat formation in a sand backfill at 1,6 mt. depth protected by concrete slabs according to the drawing show in fig. 6.1

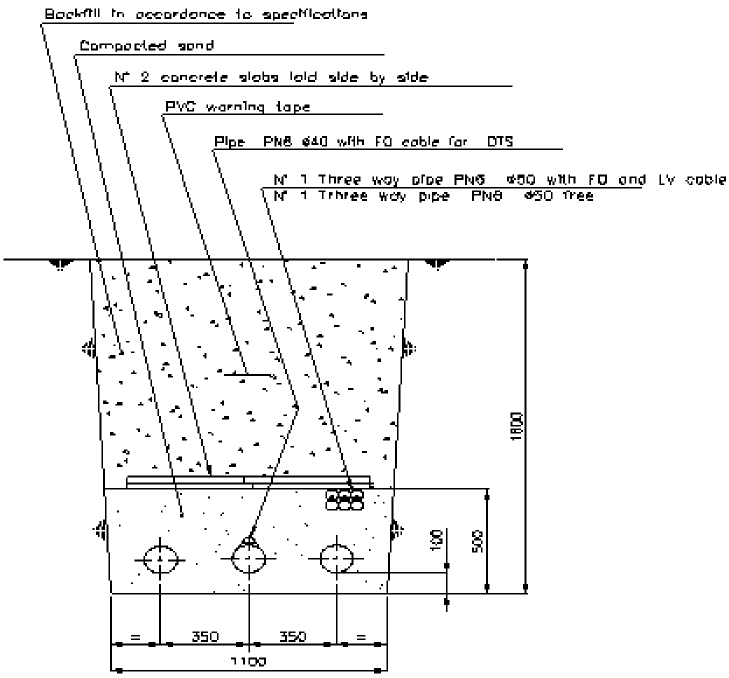

Fig. 6.1

6.1.2 Road crossings

At the road crossings made using the “open trench” technique the trench is similar to that shown in picture 6.1 but the cables are laid inside PVC pipes blocked in flat formation by concrete

6.1.3 River and road crossings(no dig technique-directional drilling)

River and special road crossings are made using the directional drilling technique and the cable are laid inside PE pipes. For the crossing of rivers Olona and Lura the pipes are filled with water (with pipes suitably fitted with expansion tanks), to improve heat dispersion.

6.2 Joints installation

The joints are installed in joint pits filled with sand as show in fig. 6.2

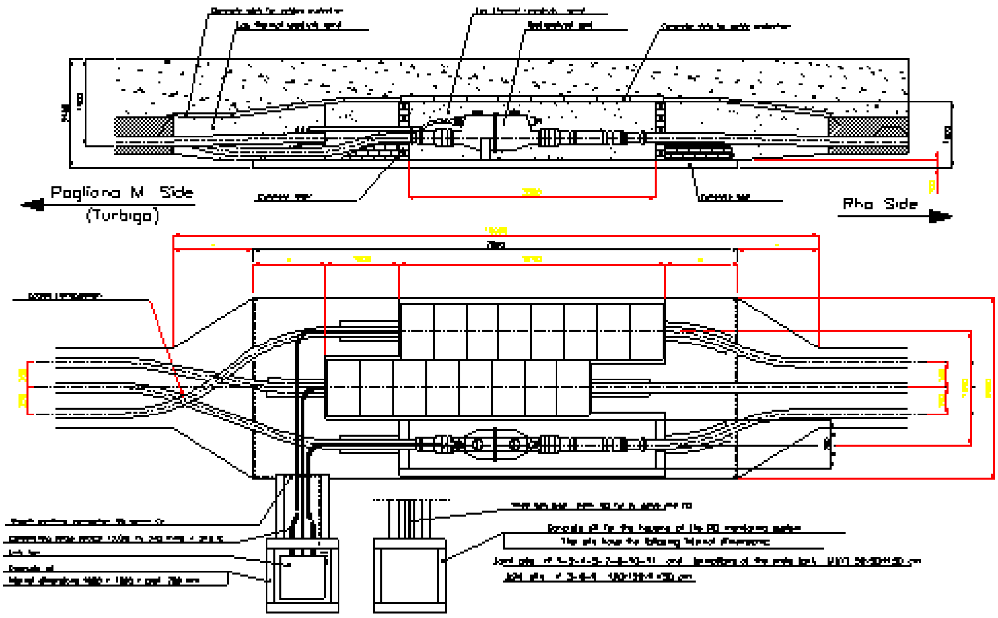

Fig. 6.2

6.4 Pictures from site during the installation

Laying operations

Pulling winch Cables laying

7. CONCLUSIONS

The realization of a meshed line, including OHL and underground cables, has been demonstrated to be the only viable solution to install a 380kV connection in the suburbs of Milan.

The adopted designs, which are not introducing any limitation to the operational parameters of a pure overhead solution, required a significant effort both in terms of technical and economical point of view. In particular the decision to have a current rating for the XLPE cables equivalent to the maximum admissible thermal rating of the OHL brought to intall a double circuit for the underground section.
The 380 kV "Turbigo - Rho" connection is considered a complex case especially because of the very difficult environment (urban areas and protected parks), overcome by a successful approval process which involved TERNA with all local Authorities to find a solution matching the requirement of improvement for the power network with the respect of the social and environmental needs.

The described meshed line was viable thanks to the network configuration, the high reliability of the XLPE cables and the developments of the Extra High Voltage cables systems in the last years.

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