The network connection of Niehl 3 CCPP - Germany's first 380 kV long-distance cable project since the Bewag projects in 2000

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ABSTRACT

RheinEnergie, the municipal utility of Cologne, is building a third block of the Niehl CCPP, located within the Cologne harbor area. With a total length of almost 9 km, the underground section of the Niehl 3 network connection will be the longest 380 kV point-to-point XLPE underground cable link built in Germany since the two Bewag tunnel projects in Berlin in the late 1990s. Besides providing the technical particulars of this new 380 kV cable system, this paper illustrates the challenges that were faced during project planning, prequalification, construction and testing.

KEYWORDS

380 kV, XLPE insulated cable, extended prequalification, DIN IEC 62067, VDE 0276-2067, distributed temperature sensing, monitoring of sheath currents.

INTRODUCTION

In spite of the network reinforcement created by the so-called German "*Energiewende*", there have not been many long distance EHV AC underground cable projects in Germany over the past 15 years. However, apart from that there are sometimes other reasons for undergrounding EHV lines arising from project specific demands like in the presented case.

In 2012 RheinEnergie decided to build a new 450 MW block at the existing plant location of the Niehl combined-cycle power plant within the Cologne harbor area. This particular location however made a solution for the network connection to the 380 kV transmission level more challenging.

In fact, an underground cable connection between the plant-side GIS and the transition point to the overhead line at Merkenich substation soon turned out to be the only viable solution.

A first attempt from RheinEnergie for finding a suitable route for the underground section resulted in a cable system length of about 7 km. However, that cable route would have lead to some extent along residential areas and therefore had been hampered by the public in early 2013. With a total length of almost 9 km, the new alternative solution proposed by RheinEnergie then turned out to become the longest 380 kV point-to-point XLPE underground cable connection realized in Germany since the two Bewag tunnel projects in Berlin commissioned in 1998 and 2000 [1]. Compared with other major German 380/400 kV cable projects commissioned over the past 15 years, the underground section of the Niehl 3 network connection - project name: NAN3 - ranks first position in terms of length (see Table 1). It also takes a particular position in terms of complexity of the environment.

Project	In service	Length	Circuits	Conductor
NAN3	2015	9.1 km	1	1x1600 Al
Bewag 1	1998	6.5 km	2	1x1600 Cu
Bewag 2	2000	5.4 km	2	1x1600 Cu
Raesfeld	2015	~3 km	2	2x2500 Cu

Table 1: Large EHV cable projects in Germany

Figure 1: Connection scheme of NAN3 - 380 kV (red) and 110 kV (black)

CONNECTION SCHEME

The 380 kV underground cable section of NAN3 is part of an overall connection scheme for the new Niehl 3 combined-cycle power plant (see Figure 1), which includes a connection to the 110 kV municipal network of the city of Cologne as well as a 380 kV connection to the transmission system operated by German TSO *Amprion.*

In order to achieve a controllable in-feed of power on the 110 kV level, a 380/110 kV 220 MVA phase-shifting transformer (PST) is connected to the plant side GIS. From there a 6 km long 110 kV underground cable connection leads to the existing *Kalk* substation on the other side of the Rhine. Within the river crossing, the 110 kV cables will be laid in a multi-utility tunnel in parallel with district heating and gas pipes.

The new 110 kV cable system will enter service in 2016. Considering the single-system layout of the 380 kV connection, this 110 kV connection provides a certain redundancy level at least for the evacuation of the generated power.

SYSTEM LAYOUT

The permit approval for the original 6 km long route had been based on nine equal lengths of about 700 m, thus forming three balanced cross-bonding systems. The first three lengths, laid in the harbor area starting from Niehl, remained unchanged in the permit process for the alternative 9 km long route. The remaining six however increased and range between 1095 m and 1160 m. Nevertheless, the design proposition of balanced cross-bonding systems had been pursued.

All in all, the system layout for the 380 kV cable connection is quite “straight forward”. The complexity however, was hidden in the ground. After World War II Cologne had been destroyed like hardly any other large city in Germany. The consequences can be still found in the ground today, thus making an undertaking like this likely even more complicated than in other environments. Besides numerous UXO (unexploded ordnance device) cases detected regularly along the route there are nowadays numerous other utility lines in almost every street and even galleries buried or constructed there in the years of reconstruction. Unfortunately, not all of them are registered to date.

Trench design

In order to keep the impact on traffic disturbance during construction as low as possible as well as with regard to the limited available space, a very narrow trench design had to be realized. Furthermore, in order to restore the open trench as quickly as possible where located within heavy traffic corridors, a fundamental obligation of the harbor authority, direct burial had been excluded as non-viable solution.

For this reason, RheinEnergie decided to go for a well-proven ductbank design, applied already at other 110 kV underground cable projects in Cologne in the past. In this design the ducts are embedded in concrete in trefoil formation, however with a spacing of 400 mm to provide a better heat dissipation and a thermal reserve for potential future requirements (see Figure 2). The laying depth of the standard trench is about 1,80 m.

Figure 2: Trench design

Following practical considerations during the installation phase, the necessary phase transposition had been executed in the GIS chamber within the last cable section laid between joint no. 1 and the GIS terminations, in order to match the phase-sequence of *Amprion’s* transmission system. For this purpose, a special design for the short-circuit-proof cable support system in front of the GIS terminations had been applied (see Figure 3).

Figure 3: Phase transposition in GIS chamber

CABLE DATA

As a result of the optimization of the trench design, expected construction restrictions, the thermal cable rating for a nominal current of 720 A and the cable cost, the 380 kV cables have a solid Aluminum conductor of 1600 sqmm cross-section. In order to obtain a light, however solid, cable design, the cables carry an aluminum laminated sheath above the copper wire screen, thus meeting the project requirements in terms of water tightness, delivery length and flexibility for cable laying. The main cable data are listed in Table 2.

Conductor cross-section	1600 sqmm
Conductor material and type	Aluminum, solid
Wall thickness (nominal)	26 mm
Capacitance	0.187 µF/km
Cable weight	16 kg/m
Screen cross-section	200 sqmm
Screen/Sheath type	Aluminum laminated with copper wire screen
Overall diameter	122 mm

Table 2: 380 kV cable data

INSTALLATION

In total 27 cable drums with a flange diameter of up to 4.3 m and 22 tons have been transported. Furthermore, 24 cable joints, 3 SF6-GIS and 3 outdoor terminations have been installed by the contractor. Both, cable laying as well as the installation of the 24 joints, had taken place under very difficult conditions depending on the location.

At the northern end cable pulling started from the transition point at the location of the outdoor terminals. Along the first 200 m of the first section several 90 degrees bends and a 4 m deep HDD crossing had to be managed. In order to cope with the maximum permissible pulling forces, the contractor proposed to use in total three hydraulic cable pushers. Each one of them was placed in a dedicated pit of 6 m x 2 m (see Figure 4).

Figure 4: Hydraulic cable pushing device

In order to assure highest safety levels wherever joint positions are located in the middle of very busy streets, two standard 20 ft containers had been placed on top of the joint pits (see Figure 5).

Figure 5: Joint pit in the middle of a street

The joint pits are 12 m long and 3 m wide. With an average depth of 2.5 m the construction process yet was quite challenging. Additionally, in the middle of the Emdener Straße, a busy 2-by-2-lane street leading through the industrial area of Merkenich had to be reduced to one lane in each direction during the construction, installation and re-filling process of almost five weeks.

QUALITY CONTROL, TESTING

During the pre-execution phase of the NAN3 project, an extensive quality control program had been accomplished that comprised

- Quality checks during cable production,
- Routine and sample tests,
- Non-electrical type tests,
- Extension of an existing prequalification (ePQ).

The tests, included in this quality control program, are based on the new German EHV cable standard DIN IEC 62067 (VDE 0276-2067) that came into force in summer 2013. The requirements from this new standard reflect the experience that was gained during the prequalification tests performed on 400 kV cable systems at CESI laboratory in Milan between 1993 and 1997. During these tests seven suppliers of EHV cable systems had been examined to establish a sufficient supplier base. The pilot character of these tests was later successfully applied in the two 380 kV Bewag projects.

System sample test

According to VDE 0276-2067 [2], within the list of sample tests, the contract parties can agree upon a so-called “system sample test” instead of a pure sample test on a cable sample only, “depending on the boundary conditions of the project”. For the NAN3 project, RheinEnergie draw this option and prescribed a test setup for this system sample test comprising two approximately 10 m long cable lengths from different production lots connected through a joint from current production. This system sample test was completed successfully in April 2014.

Extended prequalification

In the original tender for the NAN3 project RheinEnergie obliged the Contractor to perform an extension of an existing prequalification (ePQ) according to VDE 0276-2067. The test setup for this ePQ ought to include at least one piece of each type of accessory later installed in the final system, i.e. one outdoor termination, one GIS termination and two cross-bonding joints.

The requirements for that ePQ according to VDE 0276-2067 differ from those stated in IEC 62067 [3]. The major differences are stated in Table 3 below.

Besides the longer duration of the power frequency voltage test (4 hours instead of 15 minutes) it shall be highlighted that in particular for the controlling PD measurements a much higher sensitivity needs to be achieved (2 pC or better instead of 5 pC) in order to provide a higher level of confidence and to allow interpretation of the measurement results that “no detectable discharge coming from (inside) the test object” at 2 U_0. This requirement was one of the fundamental experiences from the two 380 kV Bewag projects [4].

The ePQ was finally successfully passed in September 2014. The NAN3 project however was the first one to request it acc. to the new German standard VDE 0276-2067.

Sequence of tests as per Clause 13.3.2.3.		Requirement as per IEC 62067 (2011)	Requirement as per VDE 0276-2067 (2013-08)
a)	Bending test for cables with laminated foils	Diameter of the test cylinder: 25 (d+D) +/-5%	Diameter of the test cylinder: **20** (d+D) +/-5%
b)	PD measurement after installation of the accessories	Sensitivity: 5 pC or better Background noise: not defined Test voltage: raised gradually to 1,75 Uo for 10 s and then slowly reduced to 1,5 Uo Criteria: There shall be no detectable discharge exceeding the declared sensitivity from the test object at 1,5 Uo.	Sensitivity: **2 pC** or better Background noise: **max. 1 pC** Test voltage: **2 Uo** continuously Criteria: There shall be no detectable discharge **coming from the test object** at 2 Uo.
c)	Heating cycle (voltage) test without voltage	---	This test ***must be*** followed by a PD test at ambient and high temperature.
d)	Tan delta measurement	---	---
e)	Heating cycle voltage test	---	---
f)	PD measurement after final cycle	optional after h)	optional after e), but **mandatory after h)**
g)	Switching impulse voltage test (SIVT)	---	---
h)	Lightning impulse voltage test (LIVT)	Followed by a power frequency voltage test at 2 Uo. Duration: 15 minutes	Duration: **4 hours**
i)	PD measurement after final lightning impulse	optional, but either after e) or h)	**mandatory after h)**

Table 3: Comparison of requirements for ePQ acc. to VDE and IEC

SUPERVISORY SYSTEMS

In order to allow the assessment of the 380 kV cable system under future operating conditions, the 380 kV cable system of the NAN3 project had been prepared for the use of different supervisory or monitoring systems.

Temperature monitoring

Due to the remaining uncertainty of the selected cable route, in terms of external thermal influence of potential unregistered heat sources in the vicinity of the 380 kV cables, RheinEnergie's original commissioning philosophy included a *heat cycle test* of the final installation. Within that, the future nominal current of 720 A should have been applied over a period of 20 days (load cycles), with the aim to detect potential defects and hotspots along the route under realistic future operating conditions. After a lengthy consideration process, this heat cycle test however had been skipped and replaced in favor of a temperature measurement of the route profile at "cold condition" prior to commissioning. No external heat sources or other significant obstacles have been detected.

Monitoring of screen currents

As mentioned above, the thermal conditions along the cable route are less critical than expected. However, this is not necessarily guaranteed over the remaining lifetime of the new 380 kV cable system. Therefore, and in order to maintain and guarantee the thermal transmission capability of the system during future operation, also the correct functionality of the cross-bonding systems is essential and should be checked. For this purpose, a dedicated supervisory system had been installed that monitors potential screen currents during operation.

This follows a requirement of RheinEnergie to monitor the on-line status of the numerous surge arresters installed in the cross-bonding boxes distributed over the route, especially those at inconvenient locations, for example in the middle of heavily trafficked roads, where access for maintenance may be difficult to achieve.

The key concept of this supervisory system is based on the comparison of the screen currents of all phases. For that, current transformers are installed at both terminations and at joint no. 4, where an over-ground cabinet is placed for this purpose. A detected earth fault, e.g. resulting from a potential breakdown of one of the sheath voltage limiters (SVL) would result in an increase of the two unaffected phases, thus indicating an imbalance in the corresponding cross-bonding system.

An alarm signal will then be transmitted to the control room, if a defined threshold value is exceeded. As these threshold values cannot be anticipated from earlier simulations, this SVL supervisory system must be seen as a learning system. Therefore it can only be finally commissioned and calibrated once the power plant provides sufficiently high output.

COMMISSIONING TEST PROGRAM

In accordance with VDE 0276-2067 the following commissioning tests have been performed on the final cable system after installation:

- DC voltage test of the oversheath (10 kV for 5 minutes)
- AC voltage test of the insulation (374 kV for 1 hour)
- PD measurement on all accessories simultaneously

In addition to that the following tests have been included in the commissioning test program:

- Checking of correctness of cross-bonding systems
- Measurement of zero sequence impedance

The correctness of the cross-bonding connections has been checked simultaneously with the final DC voltage test of the oversheath. For that, all cross-bonding links have been installed like in the completed system and the test voltage has been applied on an entire cross-bonding section.

HV test after installation

In accordance with VDE 0276-2067, the final high voltage test after installation has been performed with 374 kV for 1 hour. With a total cable capacity of more than 1.8 µF per phase, a resonant test equipment built-up of four 260 kV modules was required. Two series of two modules each have been paralleled in order to achieve the required loading current of 120 A. The test frequency was around 30 Hz.

The test voltage was fed through the outdoor terminations located at Merkenich substation (see Figure 6).

Figure 6: Resonant test equipment for 374 kV

In spite of the assumable negative influence coming from the 110 kV substation in the immediate vicinity of the test setup, the detected background noise level was very low against all expectations.

Together with the favorable weather conditions during the test period mid of April 2015, these boundary conditions, of course, were very helpful for the interpretation of the recorded PD patterns in order to come to the conclusion that with the chosen sensitivity “no detectable discharge coming from the test object” has been observed in any of the three phases.

As a result of this elaborate high voltage test after installation, the contractor has proven evidence of the excellent installation quality on-site.

RESUMEE

At its time of entering service in May 2015 the NAN3 project will be Germany’s longest point-to-point 380 kV underground cable connection.

After all the difficulties in relation with finding a suitable cable route through an admittedly difficult urban environment route, the NAN3 project gained speed in Summer 2013 when the contract for the supply of the NAN3 380 kV cable system was finally placed. Cable laying started in May 2014 and the installation of all accessories was completed by February 2015.

With the final commissioning of the complete NAN3 connection between Niehl 3 and Opladen substation in May 2015 this project found the basis for the commissioning of the new Niehl 3 power plant later in autumn 2015.

With all the challenges that were faced during a complicated planning and construction phase, this project can serve as a good example for future connections for similar purposes in a comparably difficult environment.

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GLOSSARY

AC: Alternating Current
DTS: Distributed Temperature Sensing
EHV: Extra High Voltage (≥ 220 kV)
ePQ: Extension of an existing prequalification
GIS: Gas-insulated Switchgear (substation)
HDD: Horizontal directional drilling
PST: Phase-shifting Transformer
TSO: Transmission System Operator