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400KV XLPE-INSULATED CABLE SYSTEMS WITH DRY PLUG-IN OUTDOOR TERMINATIONS

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ABSTRACT

The dry plug-in termination concept is well known for application as GIS and transformer applications. In order to use the benefits of this technique (no liquids, short installation time, compact design) the-plug in technology has now been introduced for EHV outdoor terminations up to rated voltages of 550kV.
These benefits were successfully demonstrated during the first 400kV reference project in Thessaloniki/Greece. After the order had been placed in December 2004 commissioning was successfully completed with the AC voltage test in June 2005 only 6 month after order intake.
This new termination design is type tested and long-term tested according to IEC 62067 standard.

KEYWORDS

Plug-in termination, outdoor termination, EHV XLPE cable

INTRODUCTION

The dry plug-in termination concept shows experiences for more than 10 years [1] with voltage ranges up to 170kV and several thousands installations worldwide under all relevant installation conditions.

Nowadays this technique allows applications up to the rated voltages of 550kV and cross sections up to 2500mm². In order to use the benefits of this technique (no liquids, short installation time, compact design) the-plug in technology has now been introduced for EHV outdoor terminations.

The technical solutions shows a socket which is well known from plug-in GIS termination. This socket is installed into a SF_6 filled composite insulator. This bushing-type element can be pre-installed and pre-tested in the factory and shipped as one piece to the installation site. This shortens on-site erection times drastically. On-site installation work is reduced to install the plug-in part of the termination on the EHV cable only. This installation work can be decoupled from the erection of the socket-bushing element which allows an optimisation of installation works on-site.

This paper gives a description of this new type of termination, summarizes the type tests carried out with this design and shows the experiences made during the first application at a 400kV project in Thessaloniki/Greece.

DESCRIPTION OF PLUG-IN OUTDOOR TERMINATION

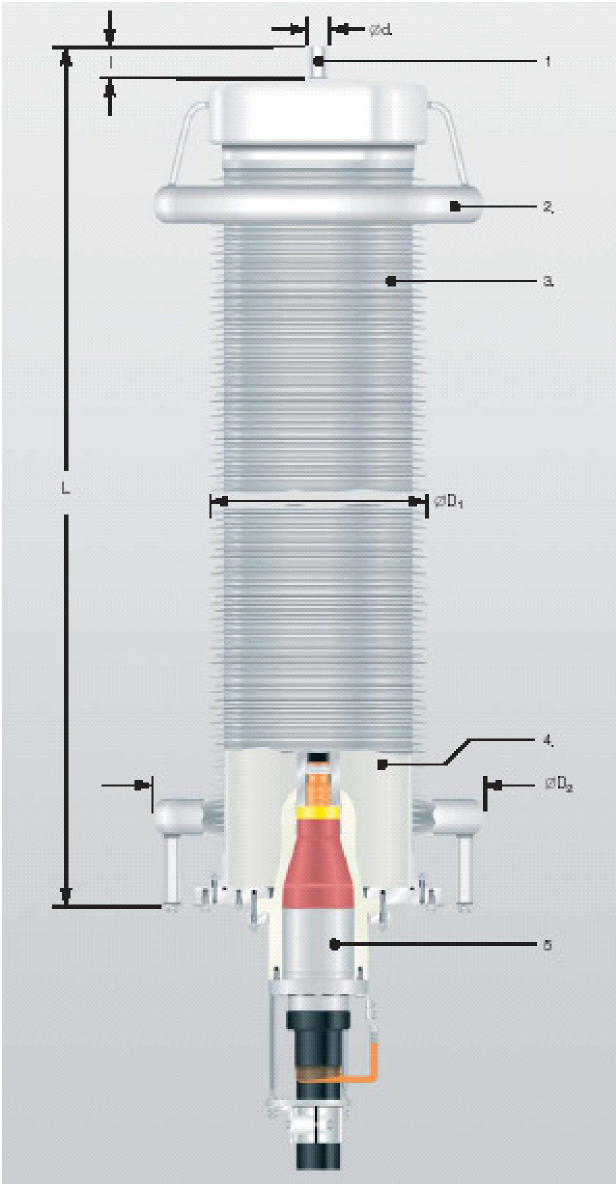

figure 1: Scheme of plug-in outdoor termination of type EHFVCS 362-550

1: top bolt
2: corona shield
3: composite insulator
4: gas filling
5: plug-in termination installed in socket

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The plug-in type outdoor termination of type EHFVCS consists of two major parts: A rigid gas filled bushing with a composite insulator and a plug-in part. The interface between these parts is identical to the plug-in termination known from GIS applications, which fulfils the requirements for "dry type cable termination" according to IEC TS 60859. A special patented internal field grading electrode inside the composite insulator leads to an similar electrical field distribution at the plug-in part inside the outdoor termination in comparison to a GIS-application.

The bushing part is totally separated from the XLPE cable by the plug-in socket made from epoxy-resin. So, the gas volume can be sealed by means of well known conventional O-ring based sealing systems. The composite insulator is chosen for its benefits regarding low weight, hydrophobic and recovery properties of its surface which consists of silicone rubber. Modern composite insulators are designed fulfil all required bending requirements. Nevertheless, an application with porcelain insulators is possible, too and was used for other projects. The conductor inside the bushing shows spring contacts which compensates the different axial thermal movement between conductor and bushing.

The plug-in part of the termination connects the cable to the epoxy-resin socket:
The “high voltage sealing” of the cable to the epoxy-resin socket is achieved by a stress-cone made from silicon rubber with an integrated stress control using a deflector. The stress cone is mechanically pre-loaded by means of a metal spring device. This device delivers a very homogenous pressure distribution on the stress cone at all electrical interfaces almost independent from the thermal expansion of the cable or stress cone itself.
Additionally the plug-in part has an integrated capacitive PD-sensor which allows an easy PD-measurement during both, routine test and on-site after installation. Inductive PD measurements are possible, too.

The current connection between the cable and epoxy-resin socket is carried out by a compression type top bolt. The current transfer of the plug-in part is delivered by means of a spring contact system. This system is well known from the GIS-termination applications. Additionally, a second mechanical spring system gives a safe locking and position control between top bold and socket.

The outdoor insulator is filled with a high-grade insulating gas. Standard application is SF_6, but SF_6/N_2 mixtures are possible, too. The outdoor termination of type EHFVCS meets the requirements of the relevant testing specifications (e.g. IEC 62067). The pressure inside the outdoor terminations can be checked by means a pressure gauge, which shows the actual gas pressure inside. A remote monitoring of the gas pressure is possible. For a rated voltage of 420kV and 20℃ the gas pressure is designed to be $4.5bar_{abs}$. For other voltage level than 420kV the SF_6 gas pressure is adjusted to the requirements. For a rated voltage of 420kV the warning level for the SF_6 gas pressure loss is $3.5bar_{abs}$.

During the development of the outdoor termination the AC voltage withstand performance was tested under reduced SF_6 pressure conditions: At an SF_6 pressure of 1bar (absolute) the design shows an AC withstand voltage of more than 460kV . The PD inception voltage for the bushing part is 450kV under these reduced pressure conditions. This allows an emergency operation of the termination even under reduced pressure conditions.

The plug-in part of the termination has been successfully tested up to AC voltages of 640kV and impulse tests has been carried out at ambient temperature and at 95℃-100℃ up to 1675kV for lightning impulse and 1240kV for switching impulses.

TYPE TEST AND PRE-QUALIFICATION TEST

This new termination design is type tested and long-term tested according to the IEC 62067 standard. These tests have been carried out with conductor cross section of 2500mm² and heating currents of 3000A which enables this design for bulk-power transmission in EHV networks.

The type test has been carried out at the independent and accredited testing laboratory IEH at the University of Karlsruhe/Germany. The testing parameters were chosen according IEC62067 for the voltage level U_{max}=550kV:

- Conductor cross section: 2500mm², XLPE insulation thickness 27mm
- GIS and outdoor termination in plug-in technique
- Heating cycle test with applied voltage of 580kV ($2U_0$) and 20 load cycles (95℃; +5℃; -0℃, 8/16h)
- Partial discharge test at 435 kV ($1.5U_0$), < 5 pC
- Hot switching impulse test on the complete set-up (1175 kV, 95℃;+5℃;-0℃, +/- 10 impulses)
- Hot lightning impulse test on the complete set-up (1550 kV, 95℃;+5℃;-0℃, +/- 10 impulses)
- Final AC test, 15 min. with 580 kV ($2U_0$)
- examination of all accessories

The pre-qualification test has been successfully carried out at the independent and accredited IPH laboratories in Berlin/Germany. The parameters were chosen according IEC62067 for U_{max}=420kV:

- Conductor cross section: 2500mm², XLPE insulation thickness 27mm, total cable length: 100 m
- Buried cable and joint, GIS and outdoor termination in plug-in technique
- Heating cycle test at an AC voltage of 400 kV ($1.7U_0$), 8760h, 180 load cycles (90℃; +5℃; -0℃, >8/16h)
- Hot lightning impulse test on 10 m cable sample (1425 kV, 90℃;+5℃;-0℃, +/- 10 impulses)
- examination of all accessories

DESCRIPTION OF 400KV XLPE CABLE PROJECT

The benefits of the short installation time could successfully be demonstrated during the first 400kV reference project. Thessaloniki Power S.A. has constructed a new power plant of 460 MVA energy production capacity which is located approximately 4.5 km from high voltage switchyard of the Public Power Corporation (PPC). The interconnection between the Thessaloniki Power Plant Switchyard and the PPC Switchyard is made by 400 kV XLPE Underground Cables. Four cables are installed between the two switchyards to give one three phase circuit plus a spare phase cable. This is the first 400 kV XLPE Cable System which was installed in Greece.

Main project data were: 18km of 400kV XLPE cable with aluminium conductor and a cross section of 800mm² installed in ducts, 16 pre-fabricated joints (buried installation) and 8 plug-in type outdoor terminations were used to connect the power plant to the 400kV grid.

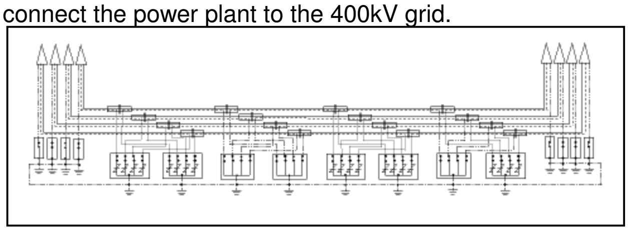

figure 2: scheme of cable system

Figure 2 shows the scheme of the cable system. Because of this special arrangement a single point bonding system was installed with earthing connections along the route in order to avoid induced screen currents. An ECC conductor according IEC recommendations provides the earth connection between the terminations. This concept allows a short time for changing to the spare phase in case of any failure situation without any necessary changes at the link boxes. Details of this project has been published in [2].

The well proven pre-fabricated composite joint design [3,4] was chosen for this project and adapted to the conductor and cable size requirements. This approach allows pre-testing of all main electrical parts and reduces installation risks and installation time on site. The chosen design is absolutely dry without any gaseous or liquid materials and maintenance free (figure 3).

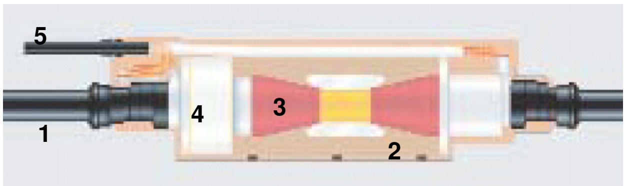

figure 3: 420 kV composite joint design,
1 cable, 2 joint main insulation, 3 stress cone,
4 screen separation 5 bonding cable

The joint consists of an insulation body made of epoxy-resin with an integrated field control electrode. The adaptation of the cable to the joint body is achieved by stress-cones made from silicon rubber with an integrated deflector. The stress cone is mechanically pre-loaded by means of a metal spring device. This device delivers a very homogenous pressure distribution on the stress cone at all electrical interfaces almost independent from the thermal expansion of the cable or stress cone itself.

Additionally, the joint design has an integrated capacitive PD-sensor which allows an easy PD-measurement during on-site after installation tests.

Further, the joint body has an integrated sheath insulation to withstand impulse voltages of 125 kV between the two joint sections and 62.5 kV to earth. This enables a cross bonding or single point bonding arrangement of the cable screens to reduce induced screen currents and losses of the AC-cable system.

For this project the joints were installed buried in joint pits. Pre-fabricated concrete elements were used to cover the joints after installation (figure 4) for protection reasons. The joint bodies itself were fully covered by liquid lean concrete.

figure 4: joint pit with pre-fabricated concrete elements

After the order had been placed in December 2004, the system components were manufactured, pre-tested and delivered in the beginning of 2005. Erection work began in March 2005, and ended in May 2005. Commissioning was successfully completed in June 2005 only 6 month after order intake. This extreme short delivery time could be reached as all major parts were shipped pre-installed and pre-tested to the job-site.

figure 5: set-up during commissioning test

1: step-up transformer	2: reactor coils
3: additional corona shield	4: HV-connection
5: HV-divider	6: outdoor termination

The commissioning test was carried out with an increased AC voltage according IEC62067 with 260kV for 1 hour. During the AC test a selective PD measurement was carried out at all accessories. There was no PD detected above the base noise level.

INSTALLATION EXPERIENCES

The main parts (bushing and stress cone) of the outdoor termination are pre-assembled and routine tested in the factory according IEC62067 standard with an AC testing voltage of 440kV ($2U_o$) for 1 hour and a PD test at 330kV.

The complete bushing part, consisting of ground plate, conductor, insulator socket from epoxy resin, field control, composite insulator and top cover has been pre-assembled and filled with SF_6 gas in the factory. During shipment the pressure has been released to 1.1bar_{abs} for safety reasons.

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figure 6: moving of pre-fabricated bushing part at job-site

figure 7: installation of bushing part on plug-in part

A special transport packaging avoids heavy mechanical shocks during transportation. The mechanical stress of the bushing part has been checked during transport by means of shock sensors. After de-packaging the bushing part is ready for installation (fig. 6). At job-site only the gas pressure has to be adjusted to the required value of $4.5bar_{abs}$.

After installation of the stress cone onto the cable core the bushing part can be installed (figure 7). The installation of the bushing part can be done within a few hours.

By means of this pre-fabricated accessory design the installation time for the terminations could be minimized. This was an important step to fulfil the customer requirements for the project time table.

Since June 2005 the cable system is operating reliable. In the meantime this design has been selected for other projects worldwide to benefit from the advantages of this new termination type.

SUMMARY

The dry plug-in termination concept is well known for application as GIS and transformer applications. Nowadays this technique allows applications up to the rated voltages of 550kV and cross sections up to 2500mm². In order to use the benefits of this technique (no liquids, short installation time, compact design) the-plug in technology has now been introduced for EHV outdoor terminations.

The technical solution shows a plug-in termination socket which is installed into a SF_6 filled composite insulator. A special patented internal field grading electrode gives a similar electrical field distribution in comparison to a GIS-application. This bushing-type element can be pre-installed and pre-tested in the factory and shipped as one piece to the installation site. This shortens on-site erection times drastically. On-site installation work is reduced to install the plug-in part of the termination on the EHV cable only. This installation work can be decoupled from the erection of the socket-bushing element which allows an optimisation of installation works on-site.

These benefits could successfully be demonstrated during the first 400kV reference project in Thessaloniki/Greece.

This new termination design is type tested and long-term tested according IEC 62067 standard.

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