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Plug-in type connection techniques on encapsulated components on high-voltage equipment up to U_m = 245 kV

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Abstract: Compact, dry plug-in type termination systems have been available since 1966 for connecting ranges of transformers, joint boxes and gas insulated switchgear with an acceptable connection technology in a space-saving, reliable and quickly assembled manner using sections of XLPE-insulated high-voltage cable. More than 2000 of these plug-in type HV-CONNEX systems are in use throughout the world in cable networks up to U_m = 145 kV. The cable termination system has been extended to Size 6-S for connecting cable sections up to a voltage level of U_m = 245 kV and cable across sections up to a maximum of 1600 mm^2 using plug-in techniques. Compact cable terminating systems, consisting of pre-fabricated and tested components, with their short assembly times, simple procedures and high reliability when assembled, contribute towards a reliable connection technology at the high voltage level.

1. Introduction

The advantages of this plug-in type cable termination systems compared with conventional, wet type SF_6 terminations are:

- easy assembly and disassembly;
- the plug-in capability of the system enables the cable to be quickly and easily disconnected from the system component in the case of a fault;
- a considerably reduced installation length of 50% compared with the conventional design;
- gas-insulated switchgear and transformers up to voltage levels of 245 kV can now be supplied ex-works with equipment connectors fitted, enclosed, tested and ready-to-connect;
- when fitting the cables at the place of installation, the opening of the cable termination box with the associated troublesome gas or oil work can be dispensed compared with wet termination in accordance to IEC 60859. The equipment bushing is pre-installed in the factory, according to IEC 60859 for a dry type system;
- as these types of cable termination systems work on the basis of solid insulating materials, any desired spatial arrangement can be realized, i.e. horizontal, vertical and even angled arrangements from top or bottom are possible. Thus, previously unknown geometries of installation windows for cable connections can be used with GIS and transformers;
- assembly times are considerably reduced compared with conventional terminations, as the se cable termination system totally dispenses with liquid insulating materials;
- at the place of installation, the gas or oil chamber on the equipment side remains sealed by the bushing that has already been fitted in the factory;
- the use of pre-fabricated and tested components provides a high level of safety and reliability;
- assembly errors are minimised, as a connection technique between system component and cable is used, which does justice to innovative high voltage technology;
- completely new concepts can be realized in future generations of gas-insulated switchgear and transformers due to the plug-in, enclosed and shortened cable termination boxes which can now be arranged at will.

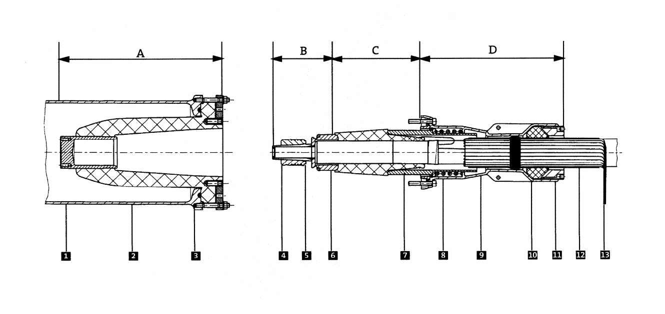
To the present day, the above advantages have been impressively put to the test throughout the world in the installation and operation of more than 2000 cable termination systems. In response to demand, PFISTERER Kontaktsysteme has developed the HV-CONNEX cable termination system in Size 6-S [1]. This system, likewise consisting of pre-fabricated and tested components, with its very short assembly times, simple procedures and high reliability when assembled, contributes towards a reliable connection technology at the high voltage level up to 245 kV and cable cross sections up to a maximum of 1600 mm^2. The system was used for the first time in Cartagena/Spain with a cable cross section of 1000 mm^2.

2. Design of the cable termination system

The presented cable termination system is used for the connection of XLPE-insulated plastic cables to electrical equipment such as gas insulated switchgears (GIS), transformers and joint boxes. As is usual with conventional medium voltage cable fittings [2], it consists of one part on the cable side and one part on the equipment side (Figure 1).

2.1 Components

The equipment connector is the component on the equipment side of the system. This is an electrical bushing, which is provided with a conical opening, the inside cone, and which is fitted in the SF_6 gas-insulated switchgear (GIS), the transformer or a plug-in type tap-off joint box in the high voltage network. It consists of the insulating cast resin body and the contact socket (Figure 1, Item A). A field control device is integrated within the cast resin bushing in the area of the contact socket.



A Component connector
1 Contact socket
2 Insulating body
3 Housing

B Contact system
4 Contact ring
5 Tension cone
6 Thrust piece
C Insulating and field-controlling part

D Housing
7 Pressure sleeve
8 Pressure spring
9 Bell flange
10 Sealing ring
11 Union
12 Shrink sleeve
13 Cable screen

Figure 1: Design of the cable termination system

The cable connector is the component on the cable side. This constitutes a coaxial system, which is arranged axially on the stripped cable end and whose components are retained by a metallic housing. It consists of the contact system, the insulating and field-controlling part and the housing (Figure 1, Item B, C, D). For its part, the contact system consists of the contact ring, the tension cone and the thrust piece (Item B). The insulating and field-controlling part (Item C) is made from highly flexible silicon (SIR). Its task is to control the electrical field at the stripped cable end and to ensure that the joint is sufficiently strong. The housing consists of the bell flange, the pressure sleeve and the pressure spring (Item D). After fitting to the cable end, the cable connector is plugged into the component connector and then bolted. This produces a long-lasting mechanical and electrical connection, which satisfies all high voltage engineering, contact engineering, thermal and mechanical requirements.

2.2 Mechanical operation

In the assembled state, the cable connector is fixed by the supports A and B (Figure 2). By this means, mechanical stresses that occur during operation are absorbed. The insulating and field-controlling part with its dielectric functions is thus free from these mechanical stresses. The same applies for the contact system. During the plugging-together process, the cable connector is automatically centred by the guide rings in the contact ring. These subsequently act as a static fixing within the contact socket. The high-current-proof laminated contacts are decoupled from these mechanical stresses and the current is therefore always transferred in the defined working area.

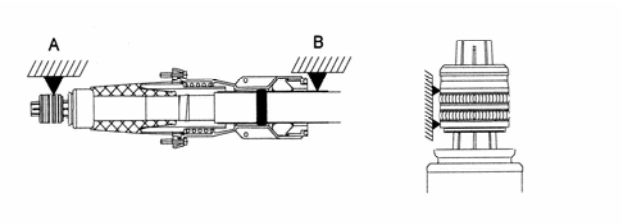


Figure 2: Mechanical operation.

The long-term characteristics of the "electrically stressed" joints are a decisive factor in the functional reliability of this plug-in termination system [3]. In this case, these joints take on the function of creepage distance and flashover distance. In the described cable termination system, the two joints, cable - insulating part and insulating part - cast resin bushing, are arranged in parallel.

2.3 Dielectric operation

The task of the pressure spring is to ensure that the necessary force is applied in the electrically stressed joints independently of parameters such as cable tolerance and thermal expansion. The three components of force, which contribute to the resulting pressure on the sealing surface, are shown in Figure 3: the spring force (F_F), the plug-in force (F_S) and the initial stressing force (F_V).

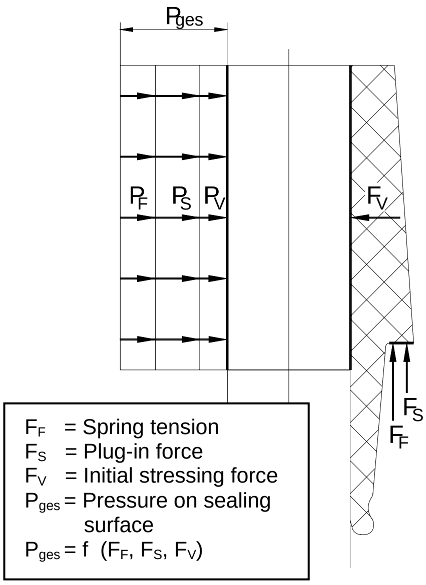


Figure 3: Components of force for ensuring the strength of the joint.

The plug-in force is a result of bringing together the conical arrangement consisting of the silicon insulating part and the cast resin connector. The initial stressing force is given by the difference in diameter of the stripped cable and the hole in the insulating part. The spring force is a result of tensioning the integral spiral spring when the bell flange is screwed on and ensures that cable tolerances and changes in volume due to temperature cycles are compensated for independently of additional forces applied such as plug-in force and initial stressing force. The electrical strength of the sealing is no longer improved above a certain contact pressure [4]. On the other hand, a reducing contact pressure does not lead to a proportional reduction in the electrical strength of the sealing when the working range follows the hysteresis [5]. A geometric capacitive field control device in the SIR-insulating part with a potential connection to the outer conducting layer of the cable is used as a field controller in the area of the stripped cable end. A high voltage electrode for controlling the field is integrated within the connector on the equipment bushing in the area of the contact system. The following criteria are particularly taken into account when matching the insulating and field-controlling part to the project-related cable:

- Maintaining the contact pressure in the electrically stressed joints and the geometry of the field control element under all operational loads [3].
- Optimised shape of the integrated field control element taking into account the cable geometry and the possible radial and axial movements of the cable cores.
- The quality of the surfaces in the electrically stressed joints, especially at the stripped cable end [7].
- Long-term characteristics of the lubricant compound used during assembly [3].

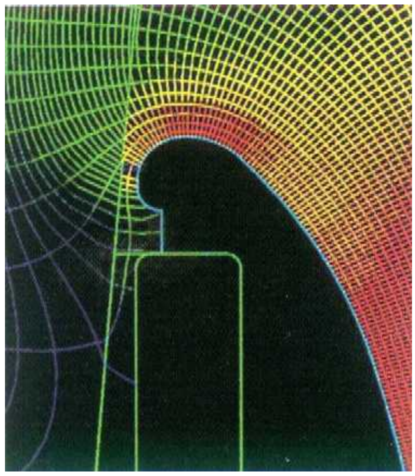


Figure 4: Illustration of field and equipotential lines in the area of the deflector.

3. Applications

The MV-CONNEX inside cone plug-in type termination of SF_6-insulated medium-voltage switchgear became established in the period from the mid 80s to the mid 90s [2]. The advantages already described in detail have been fully confirmed in practice. At present, there are more than 1,000,000 systems in use in the medium voltage sector throughout the world. This has certainly contributed to the extensive, worldwide propagation of the plug-in type High-Voltage cable termination system.

Figure 5: GIS Siemens Type 8DN9 with High-Voltage cable termination system and IEC extension adapter.

3.1 Gas-insulated switchgear

The area of application was extended more than ten years ago to include the voltage levels 52 kV and 72.5 kV. GIS systems in the voltage range U_m = 145 kV were first equipped with the plug-in type cable termination system and put into operation in 1996. Adaptation to traditional GIS systems is carried out by means of an IEC extension adapter in the conventional cable connector (Figure 5). New compact generations of systems with the highest level of functional integration are already equipped as standard with reduced-length cable connector modules for accepting the modern High-Voltage compact terminations (Figure 6).

Figure 6: GIS Type EH7M with reduced-length cable connector module (illustration courtesy of VA TECH).

3.2 Transformers

In the course of the last ten years, many of the transformers for 110 / 20 kV currently in use have been fitted with multiple elbow bushings on the low voltage side to allow termination with inside cone cable connectors in a similar manner to that described above. With this plug-in type system, the advantages of the intrinsically safe, fully encapsulated, plug-in cable termination technology are also utilised on the high voltage side, covering nearly all conceivable applications (Figure 7).

Figure 7: High-Voltage cable termination:
Transformer - Petersen coil / Transformer Siemens / PCK Schwedt.

By fitting two equipment connectors, it is possible to terminate cables, which run downwards and to the side. The upward-pointing socket is normally sealed by means of a voltage-proof dummy connector. An earthing facility is provided here if necessary. If it is required to terminate a transformer of this kind using an overhead line, an High-Voltage plug-in insulator in outdoor design can be used (Figure 8).

Figure 8: High-Voltage test and jumper terminal on the high voltage side of a power transformer (transformer SGB Regensburg).

The downwards-leading cable terminal is then sealed with the dummy connector. In addition, voltage tests can very easily be carried out, both in the works and on-site, on transformers, which are fitted with equipment connectors, using this plug-in insulator.

3.3 Plug-in joint boxes
Plug-in joint boxes for different geometrical cable configurations can be realised with few components using the High-Voltage cable termination system. The advantage of these joint boxes is that the "body" of the joint box is one unit, which is fully assembled and tested in the factory. The construction of a plug-in tap-off joint box of this kind is shown in Figure 9.

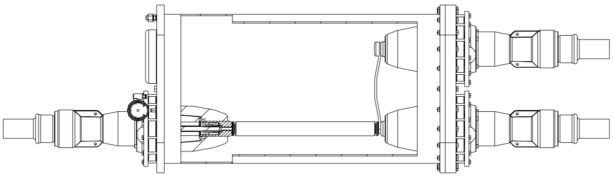


Figure 9: Sectional view of a gas-insulated plug-in type tap-off joint box U_m=145 kV.

Solutions of this kind offer an enormous advantage when cables have to be re-laid several times during a construction and conversion phase and the simple plug-in capability then becomes fully effective. However, such joint boxes can also be used for the realisation of new and cost-effective network configurations.

Figure 10: Cable installation before plug-in operation to the T-branching joint at Betchatow (Poland).

For example, with such a joint box:
- a second feeder can be connected to a GIS panel;
- a ring cable can be split and a system with a transformer can be incorporated;
- a cable affected by a fault can be disconnected and reconnected;
- an additional and simple access for cable testing purposes can be created. Each cable strand can be tested with the other cables.

3.4 Auxiliary equipment and on-site testing
Test cables (termination - cable - plug-in cable connector) or plug-in test adapters as well as blanking plugs for the voltage-proof sealing of equipment connectors are available for carrying out on-site tests. In addition, a test joint box is also available fitted with two internally connected equipment connectors (Figure 11).

Figure 11: Test joint box with plug-in test adapter.

One equipment connector is for connecting the duty cable; the other equipment connector is for connecting the test cable or the test adapter. Using this component, in conjunction with the test cable or test adapter, the prepared cable can be subjected to the specified voltage tests shortly before it is plugged in to the item of equipment to be connected.

4. Standards

The dimensions and fixings for the cable termination are defined in IEC 60859. The revision of the above norm began in 1995 with IEC TC 17. Changes for wet terminations and also a new standard for dry plug-in cable terminations were adopted. The particular features of plug-in terminations with regard to the housing dimensions are defined here. The two main differences in comparison with wet terminations are the significantly reduced overall length of the insulator, which protrudes into the equipment, and its installation in the works of the GIS or transformer manufacturer. As a result, the termination area, including the insulator, is also tested right at the initial stages of testing of the GIS or transformer. These significant differences considerably reduce constructional measures and installation effort on site for dry type cable termination.

5. Testing

A large number of tests were carried out in the course of the development of the system. Here, the main concentration was on dielectric tests for optimising the strength of the joints taking into account assembly tolerances and for optimising the field control with regard to the surge voltage loading. Heat tests for reproducing the ageing process and for simulating possible cable shrinkage were carried out in parallel. The dielectric strength of the system was demonstrated with impressive values for AC and DC dielectric strength. Not even thermal load changes of different intensity and duration were able to have an adverse effect on the dielectric strength of the test arrangement. It should be particularly mentioned that, during this special series of tests, the behaviour with short-circuit currents and multiple plugging and unplugging operations was also investigated. Limiting durability investigations were carried out at the accredited IEH laboratory in Karlsruhe, Germany [6].

6. Quality Assurance

The heart of the plug-in system is the insulating and field-controlling part, which is adapted to suit the appropriate cable depending upon the project. Silicon rubber has been used for many years in high-voltage technology and provides outstanding characteristics in terms of insulating strength, long-term temperature resistance, resistance to chemical and physical effects, flexibility and process reliability [4,7]. The highest quality demands are placed on the components used. Various measuring and testing systems were developed in-house in order to check and document the parameters of the individual process steps during manufacture. Routine testing of the components takes place in the factory immediately after the manufacturing process.

7. Operational experience

More than 2000 HV-CONNEX cable termination systems have been connected worldwide to the networks and have been operating without any problems since August 1996. These have been used both in the realisation of T-tap-off joint boxes as well as in the classical case of cable termination in gas-insulated switchgear and transformers [8,9]. In Germany, for example, several installations of plug-in type Size 5-S systems are in use in both gas-insulated switchgear systems and power transformers for the Düsseldorf Public Services Authority. Installation was carried out in this case by the company's own installation personnel. Here too, the enormous time advantages encountered during installation were impressively confirmed.

Figure 15: Plugging in the cable termination system to a T-Joint at BPSB Xian (China).

In addition, mention should be made of the operational advantages in the case of a possible fault, as now the in-house installation personnel can begin to disconnect the plug-in cable connectors to the main terminations immediately upon arrival at the substation without having to gain access to the gas or oil chambers of the equipment.

8. Summary and prospects

Conventional wet type terminations with their high level of installation effort will be replaced in the medium term by the new, plug-in SIR dry type cable termination systems in accordance with IEC 60859. This will occur as a result of the important advantages of this plug-in termination technology both in the installation phase and during operation [8,9]. Compact SIR plug-in termination systems for XLPE high-voltage cables up to a voltage level of U_m = 245 kV can be realised, which are differentiated from conventional wet terminations by the following characteristics:

- easy assembly and disassembly;
- compact construction;
- overall length reduced by 50%;
- quick and reliable assembly;
- plug-in capability;
- components fully tested in the factory;
- avoidance of liquid insulated materials;
- no need to open the cable termination box of the equipment;
- cable termination boxes can be arranged at will;
- quick and easy disconnection of the cable from the equipment in the case of a fault.

As a result, these systems offer a customer-orientated, trend-setting and economic solution. A high standard of quality and the combination of proven design features with the latest technical developments also guarantee the same high level of availability, reliable operation and long life for the

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HV-CONNEX cable termination systems Size 6-S up to U_m = 245 kV as demonstrated by previous operational experience with the plug-in type systems installed worldwide.

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