ACCESSORIES FOR HV CABLES WITH EXTRUDED INSULATION

Ref: WG 21.06 (TB 177)
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Presentation overview

- Accessories function
- Accessory design
- Accessory types
- Accessories main components
- Guide to the selection of accessories
- Tests on accessories
- Accessories installation
- Accessories maintenance
Accessories Function

- **Terminations:**
  - Accessories that connect a cable to the grid
  - The grid can be either a transformer or a GIS or an overhead line

- **Joints:**
  - Accessories that connect 2 or 3 cables together
  - The cables can be of the same type/construction or of different type/construction
Accessory Design

- The development of an accessory involves the following design aspects:

  - Electrical design:
    - the control of the electrical stresses at the cable screen interruption
    - the control of electrical stresses within the accessory, mainly at interfaces

  - Mechanical design:
    - the control of the mechanical stresses inside the accessory
    - the control of stresses transferred to the accessory by the adjacent cable and environment

  - Thermal design:
    - avoid that the accessory, due to its generally larger dimensions, becomes the hot spot for the cable system
Electrical Design

- In accessories the maximum stress occurs at the cable insulation screen interruption due to its sharp edge effect.

- Three methods or a combination of them are used to maintain the stresses below the permitted limits for the dielectric concerned.
Stress control methods

- Geometrical-capacitive stress control using:
  - A suitably shaped control deflector

- Capacitive grading control using:
  - A cylindrical capacitor cone
  - Individual toroidal capacitors

- Non-linear resistive or high permittivity stress control using:
  - Layers of insulating materials loaded with suitable fillers
Finite element computer programs are used to calculate the stresses in the critical regions of the accessories i.e. over electrodes and at the interfaces between different components and materials.
The interfaces between different components and materials are critical factors in the design of accessories.

The interface electric strength depends on the following main parameters:

- smoothness of the surfaces
- contact pressure on the interface
- type of lubricant in the interface
- electrical field distribution in the interface
- temperature and temperature changes
- quality of accessory installation
The interface electric strength is a function of the interface pressure, surface smoothness and of the physical characteristics of material interfacing.
Effect of lubricant oil on the breakdown strength of a XLPE cable silicone rubber stress cone interface

- Breakdown strength $E_0 = 9.1 \text{ kV/mm}$
  - Slope $b = 9.8$
- Breakdown strength $E_0 = 23.7 \text{ kV/mm}$
  - Slope $b = 5.9$

Diagram showing breakdown probability as a function of breakdown strength $E$ with and without lubricant.
The accessory components must support the thermal contractions and expansions due to the variation of the current circulating in the conductor.

Joints and terminations must also be designed to withstand the thermo-mechanical forces transferred by the adjacent cable/s which depend on the cable system installation condition (rigid or flexible).

Terminations must support the forces transferred by the apparatus to which they are connected.

If the accessory is filled with a fluid it must be able to support the pressure exerted by the fluid.

Accessories must support the stresses from the environment (cantilever, vibrations, seismic, ambient stresses, etc.).

Accessory support systems (e.g. joint racking, termination support) must take into account the mechanical accessory design to secure their compatibility.
Electrical Connections and Link Boxes

- Joint electrical connections must also consider control of metallic shield (screen and sheath connections for the purposes of single point bonding or cross bonding.
- Shield interrupts must withstand nominal standing voltages and impulse voltages that may occur during faults.
- Joints must have electrical connections that permit connections to link boxes.
- Link boxes:
  - Have removable links to isolate the cable metallic shield/sheath for periodic testing.
  - Connection of the ungrounded end to sheath voltage limiters, similar to 3-6 kV surge arrestors.
- Bonding cables are needed to connect shield/sheaths to link boxes. Typically, unshielded, single-phase cables or concentric bonding cables are used with 600V to 1000V insulation.
Thermal Design

- Joints have a larger diameter than the relevant cable so in order to avoid a hot spot special precautions can be adopted:
  - Use of materials with low thermal resistivity
  - Increased spacing of joints compared to the relevant cable
  - Improved thermal environment around the joints than around the cables (manholes, forced cooling, etc.)

- Terminations are generally not a hot spot due to the heat sink effect of the conductor and the location of the termination. But attention must be paid to some situations like:
  - Desert and other locations subject to high solar radiation
  - Transformers operating at high temperatures
Thermal Design

- Due to their longer thermal time constants, joints present a higher short term emergency overload capacity than the corresponding cable.

- However depending on the duration of the loading cycles, joints may present a gradual increase of conductor temperature in subsequent cycles (example of a type test in air).
ACCESSORY TYPES
JOINT TYPES

- Straight joints: connecting two cables of the same insulation type
- Transition joints: connecting two cables of different insulation types
- Y branch joints: connecting three cables
Straight joints

- Heat shrink sleeves joints:
  - They comprise several sleeves which are heat shrunk over the prepared cables
Field taped joints:

- The insulation is rebuild by applying over the prepared cable ends adhesive or self-amalgamating tapes. These tapes can be applied by hand or with a taping machine.
Straight Joints

Field moulded joints:

The field applied insulation is melted and bonded to the penciled cable ends in various manners. The joints are classified according to the method used to apply the insulation:

- Tape moulded
- Cross linked tape moulded
- Extrusion moulded
- Cross linked extrusion moulded
- Injection moulded
- Block moulded
- Cross linked block moulded
Straight Joints

- Prefabricated composite joints:
  - Two rubber stress cones are compressed over cable core and into a central cast epoxy insulator
Straight Joints

- Prefabricated premoulded joints:
  - One piece sleeve slip-on or cold shrink design
  - One piece sleeve plug-in design
  - Three piece sleeve slip-on design
Straight Joints

- Back to back joints:
  - They include two metal enclosed GIS or oil immersed terminations connected back to back
  - There are two solutions:
    - with two insulators
    - with one insulator

Note: This joint can also be used as a transition joint
Transition joints

- Polymeric to oil or gas filled paper cables transition joint:
  - Three core type

- Single core “non fed” type
Transition joints

- Polymeric to oil or gas filled paper cables transition joint:
  - Single core “fed” type
Y Branch Joints

- These joints connect three cables together. The techniques described for straight joints are adopted.

- A prefabricated composite Y branch joint is shown in the sketch.
Termination Types

- Metal enclosed GIS terminations: connecting the cable to a GIS
- Oil immersed transformer termination: connecting the cable to an oil immersed transformer bushing
- Outdoor/Indoor termination: connecting the cable to an overhead line either directly exposed to full climatic conditions (outdoor) either to a protected environment (indoor)
- Temporary termination: connecting the cable to an overhead line for a limited time
Outdoor/Indoor terminations

- Prefabricated elastomeric sheds and stress cone termination

Conductor stalk
Waterproof seal

Elastomeric moulded sheds
Elastomeric moulded stress cone
Polymeric extruded cable
Waterproof seal
Outdoor/Indoor terminations

- Heat shrink sleeve or elastomeric sleeve terminations

Diagram:
- Conductor stalk
- Waterproof seal
- Elastomeric moulded sheds
- Elastomeric moulded sleeve
- Elastomeric moulded stress control sleeve
- Polymeric extruded cable
- Waterproof seal
Outdoor/Indoor terminations

- Stress cone and insulator (porcelain or composite) termination
Outdoor/Indoor terminations

- Deflector and insulator outdoor termination
- Prefabricated composite and insulator termination
Outdoor/Indoor terminations

- Capacitor cone and insulator termination
- Prefabricated composite and capacitor stress cone termination
Metal enclosed GIS (oil) terminations

- Stress cone and insulator metal enclosed GIS termination
Metal enclosed GIS (oil) terminations

- Prefabricated composite dry type GIS termination
Metal enclosed GIS (oil) terminations

- Capacitor stress cone and insulator GIS termination
Metal enclosed GIS terminations

- Directly immersed GIS termination
ACCESSORIES
MAIN COMPONENTS

(Part 2)
Conductor connection functions:

- The connector must be able to carry the same current as the cable conductor
- The connection must be capable of withstanding the cable longitudinal thermomechanical forces
- The connection must be compatible with other accessory parts
Conductor connectors types

- Compression connectors
  - Punching
  - Hexagonal compression
  - Round compression

- Mechanical bolted connector

- Brazed connector
Conductor connectors types

- MIG or TIG welding
- Exothermic welding
- Plug-in connectors
Metallic sheath closures have the following functions:

- To conduct the capacitive and short circuit currents of the cable circuit
- To seal the connection between the cable sheath and the accessory end bell against moisture/water penetration
- To withstand the sheath thermo-mechanical forces
Sheath closure types

- **Plumbing**
  - applicable to all sheath types except thin metallic sheaths

- **Welding**
  - applicable to Al sheaths

- **Mechanical clamping**
  - applicable to thin (about 1 mm) sheaths
Joint anticorrosion protection function:

- Protect the joint metal work from corrosion
- Prevent water from entering into the joint
- Electrically isolate from earth the metallic joint shell or wire shield for specially bonded cable circuits
Joint anticorrosion protection types

- Examples of joint anticorrosion coverings

Flexible covering

Copper casing, plastic outer sheath

Coffin box with filling compound
Joints special bonding connections

Concentric bonding cable

Single core bonding cable
GUIDE TO THE SELECTION OF ACCESSORIES
Compatibility with the cable

- Required information about the cable characteristics:
  - Number of cable cores
  - Cable construction details
  - Operating temperature of the cable conductor and sheath under continuous, overload and short circuit conditions
  - Compatibility with the type of cable insulation and semiconducting screens
  - Cable electrical stresses to be withstood by the accessory
  - Mechanical forces and movements generated by the cable on the accessory
Number of cable cores

- Single core
- Three core
Cable construction details

- It is important that the correct size of accessory is selected to suit the particular cable, so the following cable construction information is required:

  - Conductor material, area and diameter and special features (i.e. water blocking or enameled wires)
  - Conductor screen diameter
  - Insulation material, diameter and tolerances (including ovality and eccentricity)
  - Insulation screen diameter
  - Screen wires, if any
  - Longitudinal water blocking, if any
  - Metallic barrier, if any
  - Oversheath
  - Armour, if any
  - Special features (i.e. presence of optical fibre or pilot wires)
Compatibility with cable materials

- Physical compatibility with the extruded cable insulation
  - The cable insulation materials are: XLPE, LDPE, HDPE, EPR

- Chemical compatibility
  - The type of insulating liquid used in the accessory may affect the properties of the cable insulation and screen material

- Compatibility with the paper insulated cable
  - In transition joints the fluid dielectric of the paper cable may come in contact with the components of the extruded cable or of the accessory
The following mechanical strains generated by the cable on the accessory are dependent on the cable construction:

- Insulation retraction (shrink back)
- Insulation radial thermal expansion
- Oversheath retraction

The following forces are dependent on the cable construction, current loading, method and type of cable constraint:

- Conductor thermomechanical thrust and retraction
- Sheath thermomechanical thrust and retraction
Compatibility with cable performance

- Required information about the cable performance:
  - Circuit performance parameters
    - Rated voltage
    - Current rating
    - Overload conditions
    - Short circuit rating
    - Basic impulse level
  - Circuit life required
    - Typically from 20 to 40 years
  - Sheath bonding requirements
    - Type of cable bonding scheme
    - Type and size of bonding leads
  - Earth fault requirements
    - Screen connections able to bring short circuit current
Compatibility with cable system

- Required information about the cable system design and operating conditions:
  - Type of cable installation
  - Standard dimensions of cable terminations
  - Type of accessory installation environment
  - Jointing limitations in restricted installation location
  - Mechanical forces applied to the accessory
  - Climatic and environmental conditions
Type of cable installation design

- Rigidly constrained
- Flexible unconstrained
- Semi-flexible
- Unfilled ducts
Standard dimensions for terminations

- For GIS and transformer terminations:
  - Harmonization of cable termination dimensions with the design of the metalclad switgear are given in IEC 62271-209 (for GIS terminations) and in Cenelec EN 50299 (for transformer terminations)

- For outdoor and indoor terminations:
  - Harmonization with the overall height of the busbar connection and bottom metalwork fixing arrangement is required

- For outdoor terminations:
  - Creepage distance to accommodate the required pollution level (according to IEC 60815)
Type of installation environment

- Buried in ground
- Jointing chamber
- Tunnel
- Above ground
- Bridge
- Tower/shaft
Jointing limitations in restricted installation location:

- Space limitations

- Time limitations
  - Road traffic influences
  - Outage duration in case of repair

- Tolerance limitation of assembly personnel
  - Extremes of temperature
  - Extremes of humidity
  - Severe vibrations
  - High noise
  - Induced voltage
External mechanical forces

- Mechanical forces applied to the accessory due to the external environment:
  - Thermomechanical forces
  - Earthquake
  - Vibration
  - Off-going busbar at terminations
  - Wind loading on busbars at outdoor terminations
  - Ice loading on busbars at outdoor terminations
  - Short circuit loading on busbars at terminations
  - GIS gas pressure
  - Angle of installation of outdoor/indoor terminations
  - Hydraulic or pneumatic pressure forces at transition joints
Climatic conditions

- Accessories are sometimes required to operate in severe climatic conditions that can affect their performance (mainly the electrical strength of outdoor insulator surface). Critical factors to be considered are:
  - Altitude
  - Air pollution
  - Precipitation
  - Salt fog
  - Moisture condensation
  - Temperature
TESTS ON ACCESSORIES
Development tests

● These tests are carried out by the manufacturers at the development stage of the accessory and include:

  ● Electrical: AC and Impulse breakdown tests, short circuit test on conductor connector and sheath connections, pollution test on outdoor insulators

  ● Mechanical: thrust test and pressure test on insulators

  ● Thermal/thermo-mechanical tests
Routine tests

Routine tests are carried out only on prefabricated accessories and are performed according to International specifications or to the manufacturer internal specifications. They include:

- Visual inspection
- Check on dimensions
- Partial discharge test
- AC voltage tests
Type tests

- Type tests include elevated voltage testing, load cycling testing of relatively short duration (20 days) and a final impulse test in order to check the performance of the accessories with the particular cable type, material, size and manufacture.
- An official type test report must be issued at the completion of the test.
The prequalification test is a system test where the cable and the accessories are installed in conditions representative of actual installation and submitted to a voltage/thermal aging of one year duration.
After installation tests

- An ac voltage test on the main insulation is normally used according to IEC Specs (DC is not effective and can be harmful)

- A partial discharge measurement of accessories can be associated with the ac test (WG 21-16, TB 182)

- Voltage withstand test on the cable oversheath, joint protection and screen interruption
ACCESSORIES INSTALLATION
Quality assurance considerations

- Quality Assurance approval for Installation
  - existence of an approved Quality Assurance System to an internationally recognised standard.

- Quality Plan including for each project:
  - the time schedule
  - the specific requirements for execution and traceability

- If purchasing separately, the User is advised to ensure that the quality systems of cable manufacturer, accessory manufacturer, and installer are compatible.
A Quality plan is required for each project including:

- Project time schedule

- Requirements for:
  - suitably qualified personnel
  - training
  - on-site storage of components and accessories
  - tools
  - testing equipment
  - constructing materials
  - assembly instructions
  - preparation of the jointing environment
  - records of the assembly works
When selecting the designs of accessories the User should ensure that training courses are available for the jointing and supervisory personnel.

It is strongly advised that personnel receive training on the particular designs of accessories and cable.
Training of assembly personnel

- Examples of the elements of a training course for assembly personnel are:
  - General training at specific system voltages with the standard range of accessories required by the User
  - Repeat training after a defined period for those personnel who have completed general training
  - Specified training on a new accessory or cable design for those personnel who have completed general training.
Assessment of proficiency of training

- At the end of the training course the proficiency of the assembly personnel is normally assessed, for example,
  - by a verbal or written examination,
  - by a practical test and preferably
  - by performing on the assembled accessories an electrical partial discharge test and voltage withstand test.

- Proficiency is recognised at the completion of training by the issue of a certificate, which should be checked by the User as part of the quality plan for a specific project.

- In many instances a kit of general jointing tools and a set of general assembly instructions is also issued to the personnel following satisfactory completion of training.
The accessory manufacturer is required to supply a complete set of assembly instructions together with drawings of the particular accessory.

- list of specified assembly tools
- specified consumable materials
- health and safety precautions
- recommendations for preparation of the assembly environment.

It is important that the User studies the instructions before work begins to ensure:

- that the workplace is correctly prepared
- that all the tools and consumable materials are available.
Special assembly tools

Most design of accessories require special assembly tools:

- To connect the conductors
  - Hydraulic compression presses
  - Welding equipment
- To shape the cable
  - Cutting equipment
- To assemble the accessory
  - Assembly machine to stretch or position premoulded elastomeric components
  - Taping machine
  - Heated moulds tools and mobile extruders for field moulded joints
Special assembly tools
Terminations on towers and poles

- Terminations can be assembled on ground level and lifted on the towers/poles
Preparation of the assembly environment
Preparation of the assembly environment
Assembly environment
**Accessories Maintenance**

- Monitoring of fluid insulation (in terminations and transition joints, if required)
- Voltage withstand test on the over-sheath and joint protection
- Voltage withstand test on SVLs for specially bonded systems
- Shelf life of accessory components for emergency spare
- Availability of accessory kits for emergency spares
- Cleaning of outdoor terminations, if required

**Periodical visual check recommended to control:**
- Damage of insulator sheds for outdoor terminations
- State of grounding connections
- Exceptional corona on outdoor terminations
- Cable movements