Mechanical forces and movements in underground cables and cable accessories

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Thermal expansion is a law of nature

Different materials have different thermal behavior, which has to be taken into account when cables and accessories for a network are to be selected. This is an important step since it significantly affects performance and reliability of the whole cable network. Thermal expansion for commonly used materials in cables is shown below:

- Aluminum 0.000023 (m/mK)
- *Copper 0.000017 (m/mK)*
- *Steel 0.000012 (m/mK)*
- *XLPE 0.0002-0.0004 (m/mK)*
- *EPR* 0.0002 - 0.0003 (m/mK)

The above mentioned thermal expansion values demonstrate that a 50K (°C) increase in temperature would increase the unconstrained length of a solid aluminum conductor by 1.15m/km, solid copper by 0.85m/km and steel by 0.6m/km. It is obvious that a variation of length and the resulting mechanical forces of this magnitude will cause some constraints on the accessories especially if the cable laying method is not suitable and the applied connection technology is inadequate. Since the thermomechanical behavior of the applied materials in cables cannot be changed it is vital to pay proper attention to the cable and accessory installation techniques.

Thermal expansion creates thermo-mechanical forces in cables

The thermo-mechanical forces in cables vary by cable type and construction, current loading and operating temperature and last but not least by the way the cable is laid in the ground.

Friction between the different materials of a cable and of the cable with the surrounding soil affects the rate of elongation of the individual materials. Therefore, the earlier mentioned coefficients for longitudinal expansion cannot be applied directly to a cable. All involved materials have to be considered together, which adds quite some complexity to the matter, since the temperature profile within a cable is inhomogeneous and depends on load and ambient conditions. Cable manufacturers may provide some approximations for the elongation based on simulation results and measurements in their data sheets. Despite the mentioned complexity, some general relations can be established.

A stranded conductor design, either three core or single core reduces some of the mechanical forces generated by the thermal elongation of the conductor material. This is because a significant portion of the longitudinal expansion of the strands is converted into spreading of the strands and thus an increase in diameter of the conductor. The ratio between radial and longitudinal expansion of the conductor is depending on the pitch of layers. As a consequence, solid aluminum conductors typically cause higher longitudinal forces in cables than stranded conductors. A long pitch on a highly compacted stranded conductor will also cause higher forces than a loosely compacted strand with short pitch. This principle can be extended from single core cables to 3-core cables. A twisted triple of cores will show a lower longitudinal expansion and forces compared to the straight individual cores. Cables suspended in tunnels or laid on galleries or in tubes have some freedom to move sideways and therefore lower thrusting forces result in the accessories.

Other sources of longitudinal forces in cables

Mechanical strains within the cable insulation material remaining after the extrusion process can lead to an insulation and/or cable sheath retraction especially where the cable has been cut to install joints or terminations. The retraction length is depending on a number of parameter. Due to the location it affects directly the installed accessories which may need to provide suitable counter measures to mitigate the risk of failure caused be the retraction of the sheath and/or the insulation.

Unintentional mechanical forces within accessories can also result from the installation process. They affect mainly joints because cables need to be moved back and forth during the installation process to install the connector onto the cable conductors. Civil works in the vicinity of joints also introduce risks for unintentional mechanical loading of the accessory when the cable is pulled aside, thereby exposing the joint to pulling forces.

Forces in the cable could compromise connector performances

The thermal expansion of a cable results in additional compression forces and bending moments within a cable accessory. Outdoor terminations are usually not much affected by this since their connection is usually flexible as well. Cable cleats however should allow the cable's sheath to move in case forces become too high.

Outdoor terminations directly connected to bus bars and separable connectors, specifically straight-type ones, may be more affected, whereas T-type connectors are again affected to a lesser extent. Since cable ends terminated with T-type separable connectors are usually arranged in a curved line the cable itself will compensate for its longitudinal expansion. However, a certain remaining and changing bending moment and cantilever force will still be applied to the corresponding bushing during expansion and contraction of the cable. Cable cleats holding the cable do typically further reduce the forces applied to the terminations.

Joints are affected most by longitudinal forces. Unless armored cables are used, the connector is the only mechanical strength member holding both cable ends together. It is obvious that ongoing cycles of compression and strain will sooner or later cause fatigue to the sensitive contact surface specifically in case of aluminum conductors. The result is a weakened and finally loose electrical contact. An increased contact resistance created by the loose contact generates significant losses and is accompanied by a significant temperature rise, which finally may even turn into a thermal runaway of the connector. Aluminum, due to its long term mechanical properties (force reduction and fatigue) deteriorates faster and specifically if exposed to mechanical stress cycles at higher temperatures.

In three core joints, depending on the construction and rigidity of the filling media, conductor expansion can give rise to longitudinal and radial displacement of the cores and eventually give rise to buckling.

In order to avoid this degradation process electrical connectors should be protected from excessive mechanical stress cycles. Joints for submarine cables are an excellent example how this could be achieved. However, the total cost of such a solution may be a limiting factor for its application.

Proper installation provide flexibility for expansion and minimize forces in connectors

The traditional installation techniques include installations directly laid in the ground, trenches, ducts, shafts, etc. but generally, the various techniques can be divided in the following groups:

- Rigidly constrained (cable laid directly in the ground or close cleated)
- Flexible unconstrained (cable horizontally snaked or vertically waved)
- Semi-flexible (cable constrained, but permitted to exhibit a controlled deflection)

Medium Voltage cables are typically laid directly in the ground. A common cable laying technique is plowing. With this technique the cable is directly laid into its final depth and in some cases also covered immediately by the plowing tool that is attached to an excavator or other similar machinery.

Since the cable is rigidly constrained by this installation technique it is important to pay attention to the thermo-mechanical behavior of the cables and also other mechanical forces especially near the accessories. Twisted bundled cables form an advantageous alternative to individual single core cables, laid side by side, as they expand less and produce lower thrusting forces.

Cable accessories are normally installed after cable laying has been finished. Since the cable has to be pulled back or shifted upward anyway to install the connector, it is very common to lay the cable in a snaky line next to the joints and even the terminations by digging a bigger opening next to the accessory (horizontal and vertical snaking). As the installation of joints and terminations are to be performed on straight cable ends, it is also important to leave sufficient space between the snaking and the accessory itself to avoid mechanical strains during the installation.

The snaking method is discussed in CIGRE publication 194 (Construction, Laying and installation techniques for extruded and self-contained fluid filled cable systems, 2001) addressing mainly high voltage cables, and CIGRE publication 669 (Mechanical forces in large cross section cables systems) addressing cables with large cross sections. Both publications can, however, also be applied to Medium Voltage cables as far as the physical behavior and design principles are concerned.

Bibliographic note: CIRED 2013 paper 0128: Measurement of the force induced by thermal expansion of conductor of MV cables and impact on MV joints

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