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Evolution of Dry Type Outdoor Cable Terminations Based on Field Experience

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SUMMARY

High voltage cable systems have a life expectation of several decades. This considerably long lifetime leads to years and years of experience, which is the backbone for any new development within the field of high voltage cable accessories. With respect to outdoor terminations as an essential equipment of cable systems, functional, safety and environmental aspects are driving the development of dry type solutions. The concept of a dry type outdoor termination itself is existing since decades and has evolved over the time into several different design groups. Established approaches are flexible dry type (with or without support insulator), hollow core dry type, bushing type and pluggable outdoor terminations. The intention of this publication is to give insights into two solutions, a well-established one following the flexible concept and a brand-new development in the family of dry type outdoor terminations using hollow core insulators, including specific design aspects and experiences in testing and field. The presented concept of flexible outdoor termination is in service since more than 20 years and offers many design variants adapted during its lifespan according to changes in system requirements, providing several application possibilities and additional features. Whereas the second dry type solution is a new design on the market with a unique single-elastomer main insulation inside of the hollow core insulator. To gain an overview on the topic of dry type outdoor terminations we compare the fluid filled and the dry type outdoor terminations. Based on the comparison the two mentioned designs and their specific characteristics are discussed. One of the main topics is the mechanical aspect within the material interfaces. For both designs, the interface between the stress cone and the cable insulation is of high importance for the operation stability. The hollow core dry type design includes an additional solid/solid interface between the stress cone and the hollow core insulator. A sensible trade-off between forces during installation and design parameters is necessary. The modularity of the flexible termination is the key to fulfil different customer requirements. A variant overview shows related specific design aspects and advantages not yet possible with fluid filled outdoor terminations. Product qualification is necessary for equipment used in power grids. Therefore, the development of outdoor terminations includes, besides design evaluations and calculations, a variety of tests to prove the correct operation and provide the necessary market qualification. This includes different normative tests, e.g. as per IEC and IEEE standard, but also customer 2022 Paris Session B1 Insulated cables PS1/Learning from Experiences 2 specific tests and internal development tests. The latter are important to prove the quality of the products - even with regard to more severe environmental stress. An overview of the testing history of the two dry type outdoor terminations is given, including a specific low temperature test stating the capability to withstand very low temperatures. Apart from type tests also routine tests are important to control the manufacturing process stability. Normally the pre-fabricated stress cone is undergoing the routine test according to IEC 60840. A different approach is used for the hollow core dry type design, where the complete pre-fabricated termination is subject of the routine test. After designing and testing cable outdoor terminations the operation experience gained through the lifetime is of high importance for the confirmation of product quality. Furthermore observation of the market and its needs leads to variations in designs of dry type outdoor cable terminations to fulfil all operational scenarios, such as temporary links, installation on towers or substations, refurbishing of old cable systems and protection by surge arresters. Examples of installation experiences including the pilot project of the hollow core dry type termination are the last topic of this paper to round up the experiences gained over the years of developing, testing and installing dry type outdoor terminations on high voltage cable systems.

KEYWORDS

HV cable accessories, Cable outdoor termination, Dry type outdoor termination, Dry composite outdoor termination, Dry flexible outdoor termination, Cable termination retrofit

1 Introduction

1.1 Evolution of cable outdoor termination

In the energy distribution high voltage cable systems consisting of high voltage cables and accessories play an important role in regard to less visible environmental impact compared to overhead lines. Especially for energy distribution in rural areas, cable system have an advantage due to the possibility of underground installation.

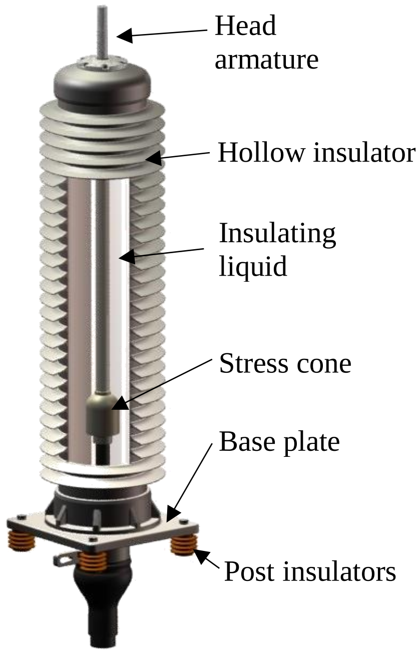


Figure 1: Oil filled termination

Cable outdoor terminations are used to connect overhead transmission lines to cable systems. They can be installed directly on the tower of the overhead line or within a substation.

Before the 1960s outdoor termination were installed with a stress cone, which was taped on site to control the electrical field [1]. With the growing use of extruded cables the first prefabricated stress cones were developed during the 1960s using a smaller core diameter than the cable insulation to expand the stress cone and control the tangential electrical field strengths [2] - [3].

Today three different major concepts are used: the oil filled terminations, gas filled terminations and dry type terminations [4]. Oil filled terminations are generally using a stress cone made of silicone or EPDM and insulating oil within a porcelain or composite hollow insulator. The standard setup is shown in Figure 1.

1.2 The dry type outdoor termination family

A termination is considered dry type when no fluid, liquid or gas, is used besides of the enclosed air volume. It can be differentiated between dry outdoor terminations such as, dry pluggable solutions with geometric or capacitive field control, dry flexible terminations, dry flexible terminations with post insulators, dry self-supporting terminations with hollow insulators.

One of the main advantages of dry type terminations is that no leakage of insulating fluid is possible, which is a major environmental advantage. No monitoring or periodic control of fluid level is necessary to guarantee the maintenance free operation. Furthermore the absence of insulating fluids improves low-temperature behaviour especially when a transmission line is switched on again after a long period of switch-off time. In principle the failure behaviour during a short circuit is causing less collateral damage due to the absence of oil.

Later a comparison shows that the concepts of dry terminations offer a wide variety of specialized versions for different applications, including not only substation and tower installations, but also routing cables for maintenance work and construction sites [5] and being installed parallel to a surge arrester enabling smaller support structures saving space on a tower or in a substation.

A comparison regarding the availability in high voltage application between dry and fluid shows that the fluid filled terminations are available from the lowest voltage of IEC 60840, i.e. U_m = 72.5 kV, up to the highest voltage of IEC 62067 U_m = 550 kV. Although there is a risk of leakage, this type is still the only available for voltages above U_m = 300 kV. Accordingly the dry type terminations are available up to U_m = 300 kV. Taking into account other international standards such as IEEE 48 there are only few dry terminations which are fulfilling the requirements of the 138 kV level of aforementioned standard.
To be able to design, qualify and sell a dry termination concept different hurdles have to be overcome. The lack of insulating liquids generates new material interfaces, which needs to be simulated and verified through testing. An example of a new approach, excluding any additional filling material, taken for the design of a dry termination with hollow insulator shows the difference to a liquid filled termination and the simulations and tests performed to design a reliable solution which can undergo the product/market qualification and routine tests. Important for a final verdict on the concept is the reliability and life time behaviour. Therefore it is interesting to understand the variety of applications which the market requests and the failure rate of the product portfolio.

2 Design a dry type outdoor termination

2.1 Challenges of dry self-supporting outdoor terminations

In a conventional liquid filled outdoor termination the overall insulating systems consists of the XLPE of the cable insulation, a rubber stress cone made of silicone or EPDM, an insulating liquid, e.g. an oil, the hollow insulator either consisting of the glass fibre tube and the silicone sheds or a porcelain insulator and finally the surrounding air. An example is illustrated in Figure 1. During installation process on site the stress cone is slipped on the prepared cable, conductor and hollow insulator are mounted and the latter finally filled with the insulating liquid.

One possible solution to eliminate the oil is replacing it by a solid insulating material, like a gel. This could be casted into the hollow insulator either during manufacturing process [4] or the assembly process on site [6]. Main function of this alternative material is to provide the necessary dielectric strength in the area around the stress cone, which could be in principal identical to a stress cone used in a conventional liquid filled outdoor termination.
Beside of using a solid insulating material instead of a liquid one, the mechanical positioning of the stress cone inside of the hollow insulator is another important difference between those designs. For the conventional liquid filled outdoor termination the stress cone is in most cases only fixed on the cable itself and has no contact to the glass fibre tube of the hollow insulator. This is not the case, if the stress cone is embedded in a solid material, leading to a mechanical contact of the stress cone and the hollow insulator. E.g., application of a gel will lead to an adhesive interface. Based on this additional mechanical boundary, further requirements are getting into focus and needed to be evaluated correctly for a proper dry self-supporting outdoor termination design:

- Sufficient mechanical fixing of the stress cone in the hollow insulator
- Appropriate contact pressure between stress cone and cable
- Alignment between cable and stress cone respectively hollow insulator

Considering those aspects the development of a new concept for a dry self-supporting outdoor termination is presented in the following chapter.

2.2 A new approach of a dry outdoor composite termination

Instead of using an alternative solid insulating material to replace the air volume in the area of critical dielectric stress, the concept of this dry outdoor composite cable termination comprises a bigger stress cone made of silicone. No other insulating material, beside of the residual air volume in the hollow insulator, is used. Thus, the stress cone avoids any critical field strength in air inside of the hollow insulator. Positioning and fixing of the stress cone, a pre-moulded component, in the hollow insulator is realized by friction, resulting in direct contact of the stress cone and the glass fibre tube. Those interfaces contribute to the overall mechanical and dielectric function of the outdoor termination. In Figure 2 the principal assembly of the termination is shown. Hollow insulator and stress cone form one pre-fabricated main unit, ready to be installed on the cable on site.

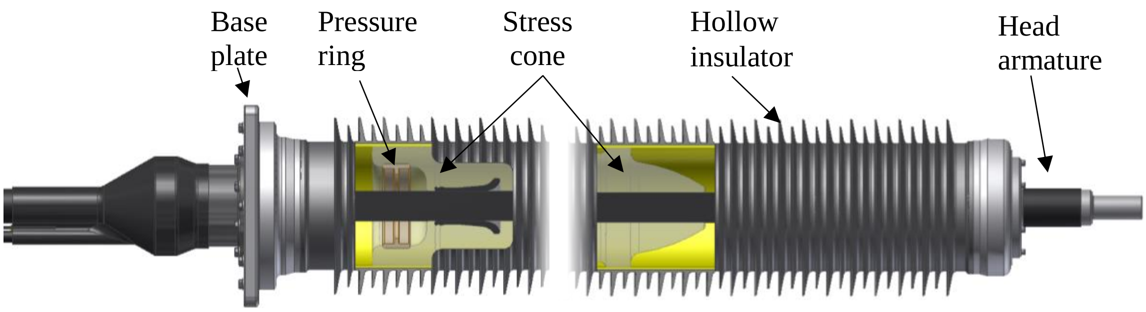


Figure 2: Basic concept of the dry outdoor composite termination without additional insulating material

An important functional aspect is the sufficient mechanical fixing of the stress cone in the hollow insulator. Correct position needs to be ensured, so that the deflector in the stress cone suits the peeled edge of the outer semi-conductive layer of the cable. Regarding the installation of the termination on site, the pre-fabricated main unit is slipped on the cable. During this process, the stress cone needs to withstand the mechanical forces, resulting from the necessary expansion of stress cone and the friction between cable and the silicone.

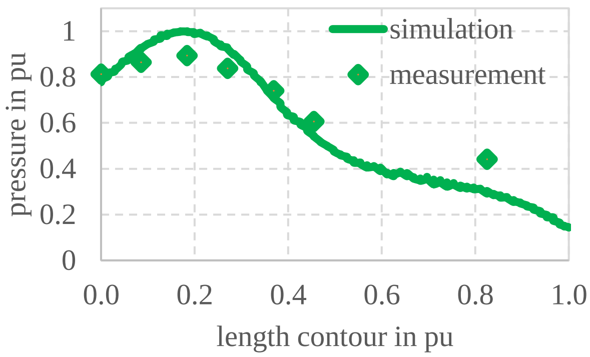
Knowing the maximum occurring mounting force, the stress cone can be adopted to fulfil this requirement. A plastic ring helps to reach the necessary withstand capability by increasing the contact pressure and therefore the friction between the stress cone and the glass fibre tube. Finally, a test has been done to determine the maximum force the design can handle without release of the stress cone and validating its reliable operation. A photo of the test setup is shown in Figure 3.

Figure 3: Test to verify the mechanical fixing of the stress cone in the hollow insulator

A modified stress cone with an embedded metal plate in its centre, representing the point for applying the mechanical force, is pushed until it starts to slip.

Beside of having this well fixed stress cone, guaranteed by a high enough contact pressure and friction towards the hollow insulator, also the contact pressure at the interface of the cable and the stress cone needs to be taken into account. In general, contact pressure at such an interface is required for the dielectric functionality of the system. With increasing pressure, the dielectric withstand capability is increasing and saturating above a certain limit [7]. Therefore, falling below a minimum pressure will lead to a dielectric breakdown. On the other hand, there is also an upper limit, since too high pressure can cause irreversible constriction of the XLPE-cable insulation, in particular under high temperature conditions [8]. For the conventional oil-filled termination the material, geometry of the cable and stress cone and the temperature are influencing the contact pressure. Regarding the new dry outdoor composite design, the inner diameter of the hollow insulator is an additional parameter, because there are regions of the stress cone with an inner contact to the cable and an outer contact to the hollow insulator. This configuration is comparable to dry type pluggable terminations for GIS or transformers, where the stress cone is in between the XLPE of the cable and the epoxy resin of the socket. Therefore, behaviour of those two material interfaces and the system itself is well known, but need to be transferred correctly to the new application of an outdoor termination.

To fulfil the mechanical and dielectric requirements in both interfaces, a balanced design considering all the influencing parameters is required. Mandatory for achieving such a design is a combination of mechanical simulation and testing. In Figure 4 the contact pressure at the interface of the cable and the stress cone (green contour) is presented for the illustrated area of the stress cone. The pressure is normalized based on the occurring peak value.



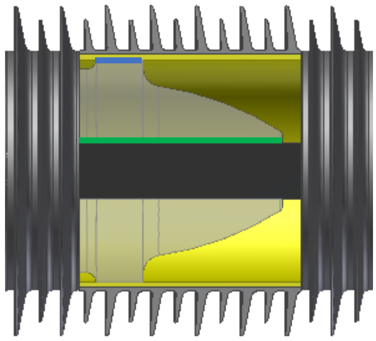


Figure 4: Contact pressure at the interface of the cable and the stress cone (green contour)

Qualitatively, there is a pressure-peak underneath the silicone ring of the stress cone. The additional outer boundary limits the possible radial expansion and therefore pressure at the cable surface is increasing. The quite good fit of simulation and measurement provides the opportunity of a faster and more efficient development process. Extensive experimental iteration can be avoided.

For the same area of the stress cone the temperature influence of the inner and outer contact pressure are investigated. Simulation results are pictured in Figure 5. Again, the green graphs in the left diagram represent the contact pressure at the green contour in Figure 4. Blue graphs on the right side suit to the blue contour in Figure 4, namely the interface between the stress cone and the hollow insulator. Values are normalized based on the corresponding appearing peak at room temperature. The temperature scenarios are representative for a high respectively a low temperature scenario. Such a scenario is depending on the variant of the outdoor termination and the cable itself, thus it is just an example to show and explain qualitatively the temperature influence. In the high temperature scenario a maximum allowable ampacity of the modelled cable and a high ambient temperature were chosen to have a realistic temperature distribution in the termination as an input for the mechanical simulation. For the low temperature scenario, a uniform low temperature was used, thus representing an unloaded cable system under cold ambient conditions.

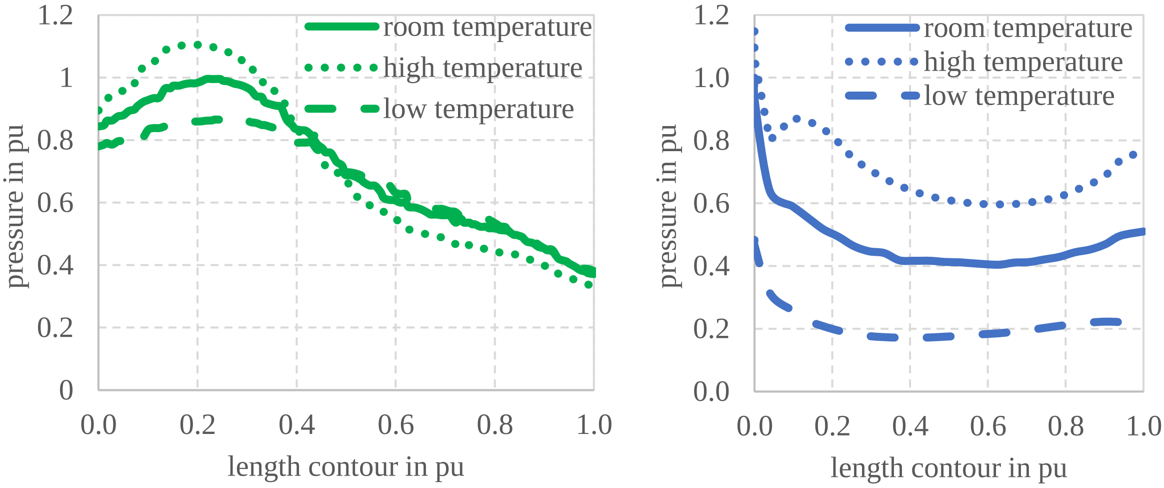


Figure 5: Contact pressure at the interface of the cable and the stress cone (green contour – left). Contact pressure at the interface of the stress cone and the hollow insulator (blue contour – right).

Focusing on the inner interface, contact pressure underneath the silicone ring is increasing with temperature. The peaks differ slightly in the range of ~ + 10 % respectively – 15 % compared to room temperature. For the outer contact interface, the pressure is more temperature sensitive. E.g. between the length of 0.4 pu up to 0.6 pu the pressure at high temperature is 3 times the pressure at low temperature. This needs to be considered, when choosing the correct stress cone dimensions.

3 Dry type termination testing and qualification

Product qualifications are necessary for equipment used in power grids, in order to verify design, operation and safety of the equipment. They also provide the necessary market qualification. Therefore, the development of outdoor terminations includes, beside design evaluations and calculations a variety of tests starting with research and development tests, followed by design tests, as shown previously. Then, routine tests, official type tests, prequalification tests and additional tests to cover special requirements and applications according to customer and market specific standards are needed to ensure the relevant homologation.

3.1 R&D and design tests

During the development of dry type outdoor terminations there are some new challenges to be achieved. Research and development tests as well as design tests are therefore needed to support the different steps of the development process.
For the flexible dry type cable terminations (with or without support insulator), R&D tests regarding the material design and mechanical tests on the support insulator are very important [9]. For some modular construction, gluing tests are needed in order to choose the suitable glue with the required mechanical and dielectric properties.
For the new dry outdoor composite design, in addition to the development tests mentioned in chapter 2, many different mechanical and electrical tests have been performed, in order to develop and verify the production and installation process. The execution of slip-on tests for different cable geometries and electrical tests like e.g. lightning impulse voltage step tests and partial discharge measurements and AC-long durations test supported the development process

to define the ideal grease, the safety margin, the installation process and also to verify the feasibility of the routine tests after production.

3.2 Routine tests

Figure 6: Routine test setup

To ensure the quality of every single high voltage cable termination, the main insulation respectively stress cones are normally subjected to routine tests e.g. according to IEC 60840. This step after the production is very important, since it enables to control the manufacturing process stability. In the case of liquid filled outdoor terminations it is usual, for practical reasons, to perform the routine test only on the prefabricated stress cones. A similar approach apply to dry flexible terminations, however the main insulation is designed to work without an additional radial insulation, like e.g. the insulating liquid. A different approach is used for the presented dry outdoor composite termination, where the complete prefabricated termination, consisting of the hollow insulator, stress cone and base plate, is installed on a cable and subjected to the routine test, see Figure 6. In this way, operational conditions are simulated as close as possible.

3.3 Type tests, customer and market specific tests

Standard type tests and system type tests according to IEC 60840 are needed in most cases as a minimum requirement to qualify cable outdoor terminations. For certain customers and markets additional tests are required, for example to prove the quality of the products even with regard to more severe environmental stress. Some of these tests are standardized, some need to be developed or are based on available standards and agreed with the customers.

In the case of the flexible dry type cable terminations with support insulator, many different standard as well as customer and market specific tests have been performed. The standard tests includes IEC 60840, IEEE 48, ICEA-S108-720 and AEIC CS9-15. Moreover, special low temperature tests [10] (see Figure 7), wet power frequency withstand voltage tests, salt fog withstand voltage tests and tests with ultra-bendable HV cables have been performed [11].
In addition, flexible dry type cable terminations without support insulator were also tested in order to cover grid operator specific requirements for temporary installation cables for U_m = 245 kV with a limited basic insulation level. The new dry outdoor composite termination has already been successfully type tested according to IEC 60840 in the voltage levels of U_m = 123 kV, 145 kV and 170 kV each (see Figure 8).

Figure 7: Cold chamber test set-up

Figure 8: Type test setup

4 Diversity of dry type termination applications

Dry type terminations are more versatile compared with liquid filled terminations, due to the different available designs of dry terminations. Dry self-supporting outdoor terminations with a pre-fabricated main unit of hollow insulator and stress cone are an ease to install on site. There is no gluing needed on site, no filling of oil or other filling materials, thus allows the shortest installation times on site. The market acceptance of such terminations can be considered higher, as their appearance from the outside is the same as the liquid filled terminations with composite hollow insulators.

The concepts of the dry flexible termination offers a multitude of combinations for a variety of different applications, see Figure 9:

① Dry flexible termination
② Dry flexible termination with a post insulator
③ Dry flexible termination with cable clamp and post insulator
④ Dry flexible termination with surge arrester

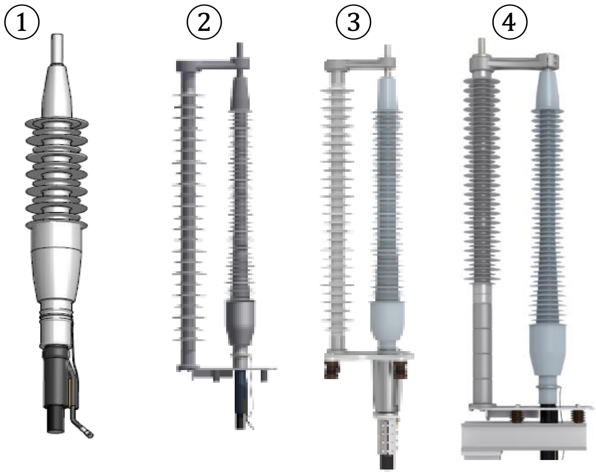


Figure 9: Overview dry flexible termination and its derivate

Dry flexible terminations are used for routing cables combined with another flexible termination or a pluggable cable connector. Routing cables are suitable for temporary cable links in case of maintenance of substations, in case of emergency or for on-site testing. They are installed ready-for-use on a cable drum for short reaction time.


Figure 10: Dry terminations with surge arrester on tower

Installing post insulators in parallel to the flexible termination gives an increased mechanical strength for long-term usage on towers and substations. The usage of a cable clamp enables the installation on the ground without the need of a scaffolding. Especially when installing on towers installations, this is an additional benefit in regard to downtime and erection costs. Using a design with integrated surge arrester increases the safety of the cable system in case of overvoltage as it is positioned as close as possible to the cable system which shall be protected, see Figure 10.
Moreover it allows a compact design for substations and towers compared to standard configurations with surge arresters, see Figure 11 and Figure 12.

Furthermore, the concept of the flexible termination offers the possibility to be used as refurbishment solution for outdoor terminations of any kind, fluid or dry type. In case of refurbishment, the modularity of the flexible terminations allows to replace an old termination in all of the mentioned applications. No matter if installed on the tower, in a substation or with a surge arrester in parallel to increase the security of an older cable system. The installation of the refurbishment solution is done on the existing cable without additional ground work, the need of a new cable and a joint or an adaption of the supporting structure.
Every retrofit termination is adapted to the existing termination and cable, taking into account the critical dimensions, such as length of peeled insulation, positioning of semi-conductive edge, crimped conductor and base plate hole pattern. Therefore the retrofit terminations are engineered to fully replace old terminations.

The modularity of this solution can be seen during a project in Spain where six terminations on a tower (Figure 11) and six terminations in a substation (Figure 12) has been replaced with the retrofit solution based on the flexible termination.

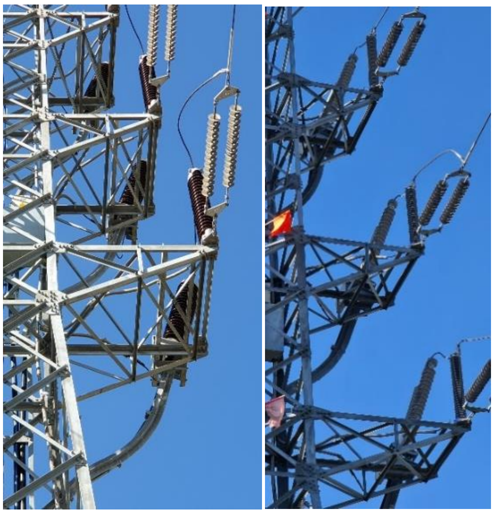


Figure 11: Retrofit on tower

Figure 12: Retrofit in substation

The modularity of this dry flexible termination and its acceptance in the market of the different solutions can be seen in the overview in where the percentage per application is shown of the last two years. The change in percentage of the variants is very much project driven.

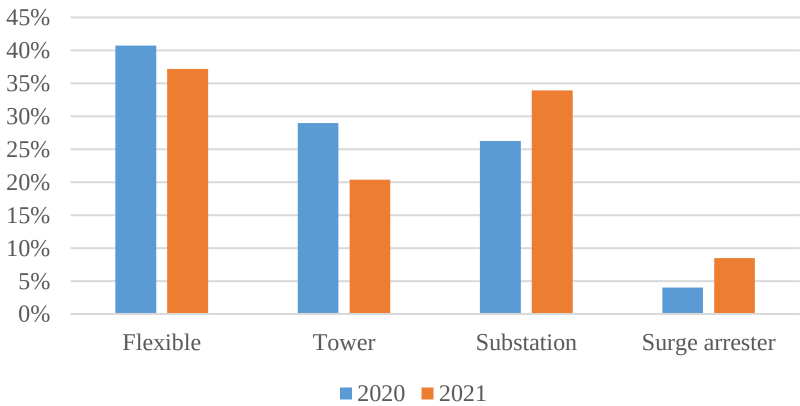


Figure 13: Percentage per application of dry type termination 2020/21

Life time of all cable accessories can be limited by factors such as bad installation quality, overvoltages caused by lightning, ageing of the system etc. Dry cable terminations have proven to be reliable over the years of usage. Looking at the sales figures of a European manufacturer of dry flexible terminations of the years 2013-2021 and the claims of the same period, a failure rate of smaller than 1 per thousand installed products is observed.

5 Conclusion

The dry type outdoor cable termination family includes many different designs. This allows to cover a wide range of applications, system and environmental requirements. The new dry outdoor composite termination design complements the dry type terminations family with its installation simplicity, which drastically reduce the installation time and therefore the project costs. Hence, it is reasonable, for the choice of a dry type outdoor cable termination, to consider different aspects like system design, ambient and installation conditions, safety requirements as well as the involved costs. The increasing demand for dry type terminations with all their specific advantages, like environmental friendly and safe design, leads to growing acceptance in the market. The know-how gained during many years of development, testing and field experience with dry type outdoor terminations will support future developments even for higher voltages than U_m = 300 kV.

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