Reliable connector solutions for large cross-section aluminum conductors

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ABSTRACT

Copper is becoming a costly and scares resource. Hence, there is a tendency to replace copper with aluminum as conductor material in (E)HV underground and submarine cables. Because aluminum is susceptible to surface oxidation connector solutions must be carefully designed to ensure long-term stability, in particular for large cross-section aluminum conductors composed of many individual wires. Welding is by many today considered to be the only reliable connection method for such conductors. In this paper a new approach for connecting large cross-section aluminum conductors is presented. The method has the prospects of being reliable, safe, and fast.

KEYWORDS

Connectors, Al conductors, HV cables, EHV cables, welding, cold spraying

INTRODUCTION

The future society is based on electricity as the primary source of energy. Key sources of this energy supply, like offshore wind turbines, huge solar cell parks etc. will often be located far away from centre of usage. Hence, there is a strong growth in the need for new, high-capacity interconnection lines as well as local transmission lines. Nowadays, more and more of such new transmission lines on land are installed as underground cables and for cost reasons and because of scarcity of copper (Cu) many high-capacity cables are based on use of aluminum [Al] conductors.

To meet the ampacity requirements for such high-voltage cables the conductor cross-section must be large. Today cross-sections of 3,000 mm^2 or even bigger are becoming common [1]. Cross-sections of 4,500 mm^2 was presented at the Cigre 2022 Session, and even bigger conductor dimensions can be expected in the future.

Al is susceptible to fast oxidation, thus immediately creating an insulating layer on the wire surface. The electrically insulating oxide layer is beneficial to reduce skin effect phenomena, hence lowering AC resistance on large cross-section conductors. However, the oxidation phenomena create significant challenges when a reliable connector solution is to be designed. Main challenge is to ensure stable electrical contact to the innermost wires in the connector system.

Several different approaches already exist for connecting Al conductors [1].

Shear-bolt connectors are the most common solution due to their simplicity and ease of use. For their use in connecting larger Al conductors the main challenge is to ensure good, long-term connections to all the individual wires. Some companies are using a plurality of shear-bolts for larger Al conductors up to approx. 2,000 mm^2 in cross-section. This is combined with use of lubricants to reduce risks of having oxygen later penetrating to contact points. Otherwise, contact points can be vulnerable to oxygen exposure due to thermo-mechanical movements by the two interfacing bodies at load variations.

Crimped solutions are not so common for larger cross-section Al conductors due to lack of contact to innermost wires in the connector region [1].

A general concern for both shear-bolt and crimped solutions, when used for connecting larger cross-section Al conductors, is that they perform well when being newly installed, but the resistance to the innermost wires can gradually increase over time due to oxidation, in particular if the system has been exposed to short-circuits. Most installed systems are operated far below the maximum load level, which the systems are designed for. Likely, this is one of the reasons for why this failure mechanism has not been seen much in installed system but seen only as a tendency under long-term tests.

Welding is the most widely used solution for connecting large cross-section Al conductors and by some considered to be the only reliable method for connecting very large cross-section Al conductors [1]. By welding all individual wires at the conductor ends are physically made into one body. Hence, for connectors making use of welding there is no risk of reduced or lost contact between individual wires due to oxidation at vulnerable contact points.

However, use of welding for connecting large cross-section Al conductors also has its drawbacks. The welding process must be carried out very carefully and slowly to avoid that the heat from the welding process is damaging the nearby insulation of the cable. Forced cooling is necessary to protect the insulation from heat damage. Very skilled welders are required to carry out the welding process and there is lack of such specialist. Furthermore, the process creates un-healthy fumes and risks of fire. Some utilities [1] does not allow welding to be used at installation of their systems, and others are considering the same policy.

Hence, there is a need for developing an alternative method for connecting large cross-section Al conductors.

BASIC WORKING PRINCIPLE

A main benefit of the welding process is that it physically integrates all wires, hence avoid issues related to surface oxidation. In the solution proposed in this paper the same basic feature is accomplished by building a metallic coating on the end-facet of the two conductors to be connected. This coating is made by spraying very small metallic powder particles on the end facet of the conductor in a cold process, called cold spraying [CS]. Since this process can be carried out at low temperatures all the drawbacks of the welding process are avoided. The two coated end surfaces are connected by a so-called flex-element. All electrical contact points of the system are silver [Ag] coated. Hence, the connector solution has no vulnerable points for potential surface oxidation. Fig. 1 shows the basic principle of this connector solution.

COLD SPRAYING TECHNOLOGY

The connector approach is based on the use of cold CS as