TE’s Raychem First Aid connector

From an Idea to the Product – Technical Review

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Abstract

The energy grid consists mostly either of overhead lines in rural landscapes and power cable in urban districts. Both are complex systems fulfilling several electrical, mechanical and thermal requirements for energy transportation. To create an electrical connection is a difficult and specialized process, taken over by trained and well-equipped staff. But in certain cases, a quick and easy installed connection is needed.
For example, in rural landscapes the distances to the failure can be too far. Repair can take several days, also delaying the reactivation of the energy grid.

This document explains the development process of the First Aid connector. It is a temporary connecting solution for energy cable or overhead lines. The main advantage of this specific connector is related to the fact that it's made of 3 components only. Therefore, it can be installed quickly and easily without any special tools. Just a heat source for shrinking is needed.

In this paper, the general characteristic of the First Aid connector is investigated as well as its basic electrical properties like the resistance and possible tensile-forces. Thus, the First Aid connector proves its capability as electrical connector.

In order to develop a strong mechanical solution for connecting overhead lines, TE Connectivity (TE)'s engineers developed a different design, mechanically optimized First Aid connectors. Lastly, further technical data are derived from the results for practical application of this product.

General Background

TE's reputable Raychem cable accessories product family is available for Low and Medium voltages up to 245 kV. Its product portfolio covers many different material combinations with special characteristics and application, with over 40 years of field experience.

One of TE’s core competencies is the heat shrink technology. It allows simple and convenient installation of insulating sleeves. Typically, a cable accessory kit consists of a metal component to connect or to access power cables, e.g. a connector or lug. Also, the kit needs insulating sleeves to cover the connector for providing insulation.

Furthermore, the sleeve has to protect the connection from moisture, electrical and/ or mechanical stress. TE's heat shrink products' advanced technology and specific composition, enable their durability and long service life in harsh environments. They continue to perform robustly in the field more than 30 years after installation. The sleeves fit on the metal components and function reliably during shrinking and in service.

For example, our special insulation sleeve with a high grade of crystallinity is very robust and hard. Thus, it can develop high mechanical, internal forces. It is mainly used for protection in outdoor applications where electrical and mechanical stress occur at the same time. Failure of one component would accelerate failure of the cable accessory.

This leads to another application dealt within this paper. The used thermoplastic polymer is one of the least complex kinds of plastic. However, it is not known for its natural shrinking property. TE Connectivity's engineers knowledge, experience and innovation ensured the development of a heat-shrinkable solution.

Current Technologies

As used in many cable accessories, the up-to-date connecting solution of energy networks is using metal components. For underground power cable, electrical connection between two cores are established by traditional crimping technology, or by the convenient and range-taking shear-bolt technology. Crimp connectors or lugs are individually designed for one cross-section. With special tools, the crimp metal parts are crimped on conductor. With the mechanical deformation, a solid and stable connection is produced.

Mechanical connectors and lugs have one or more bolts to screw on conductor. The head of the bolt shears at a certain torque and a connector without sharp edges is left. For the shear-bolt, a torque wrench is used which is convenient to work with.

For overhead lines, we mostly use crimping technology since a solid and mechanically strong connection is needed. Additionally, only metal components are connecting overhead lines due to high forces occurring there.

The advantage of metal components is the conductivity, the mechanical robustness and thus a long lifetime. Nevertheless, special tools, trained staff as well as certain amount of time is needed to install those complex connections under difficult circumstances in air or in ground.

The Idea took root

The idea of the First Aid connector was born after the occurrence of the hurricane in the Philippines back in 2013. TE's Engineers brainstormed and discussed matter of the news. Less machines and motors can be used. After such a natural catastrophe a quick restoration of the electric power grid is a must. In the Philippines, the power distribution grid has been hit hard by the hurricane, as it is mainly relying on overhead lines. The advantage of overhead lines is that repairs can be realized with much less efforts in comparison to underground lines due the unavoidable excavation.

Thus, an idea of a simple and quick-to-install electrical connector was born.

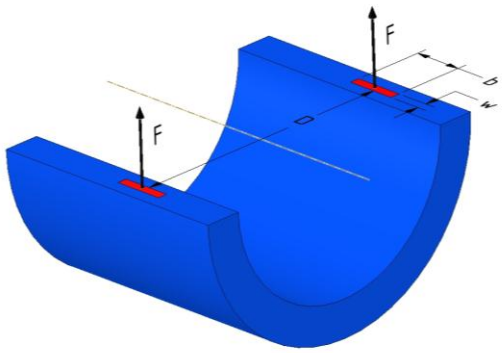
Conventional, metallic connectors for overhead lines need high compression forces offered by special tools and professional jointers. So this could not be a quick and easy solution. The group of TE's engineers started to develop a concept to connect any electric power line with a heat shrink sleeve. We believe that even in the worse crisis situation, heat or fire and knife could be available to allow the installation.

Of course the Firs Aid-Connector's application is not limited of natural disasters situations. It has been developed for all needs of temporary connection. For example, in Turkey or Scandinavian countries the energy grid consists to a high percentage of overhead lines. The proper repair of a defect section is sometimes hard due to climatic situation (extreme heat or snow). Another point is the rural landscape in those countries, so the travel from the trained personal to the location of grid breakdown could take more than a day.

In such cases, a quick-to-use, temporary connector to reestablish the power grid in a short time period can be a welcomed solution.

Consequently, the special designed insulation sleeve should fulfill the requirements for an electrical connection and should replace a metallic connector temporarily. It offers with its strong mechanical properties the opportunity to create a connection between two electrical lines, whether overhead line or underground cable. This sleeve offers an up to 10 times higher interface pressure in comparison to other heatshrink solutions.

Interface pressure is defined as the pressure in the wall of the sleeve, which is created with the shrinking process. The interface pressure results in the recovery force, another way to measure how strong the sleeve is shrinking back to its recovery diameter.



First prototypes and installation trials showed great potential of the concept First Aid connector. In 2014, this invention has officially been sought and accepted as idea for the international patent WO 2016/012052 A1. The work described in this paper deals with the detailed analysis of electrical and mechanical properties of the First Aid connector.

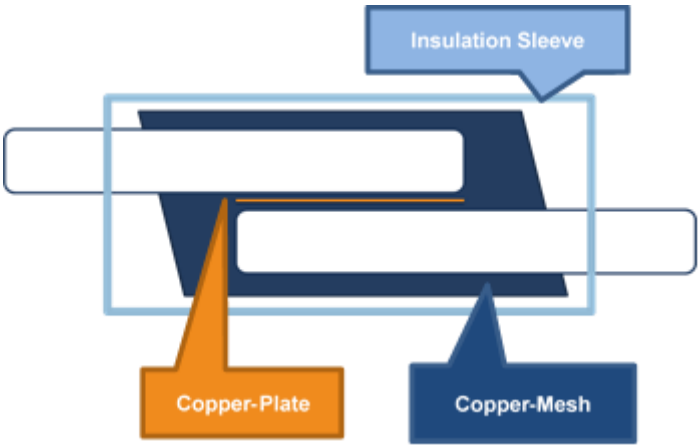
Technical Requirement

In order to develop such a temporary connecting solution, the requirements for an electrical connector for power lines has to be highlighted. An electrical connection is established by a mechanical connection between 2 different overhead lines or underground cables. Thus, a certain mechanical force has to be created on the splice.

The connection must be firm and solid, which results in both good mechanical strength of the connection and low electrical resistance. Then, the connection generates less heat loss. The thermal aspect will be explained in detail, as the polymeric component insulation sleeve is more influenced by heat than a metal component.

Summing up, a firm mechanical connection is a major requirement for the First Aid connector to guarantee good electrical properties and to stay with thermal limit given by the thermoplastic component insulation sleeve.

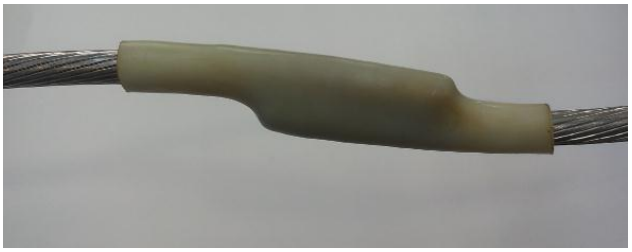
Design of the First Aid connector



The First Aid connector consists of three components. First there is the copper-plate which has a special, crated surface to dig mechanically into the surface of the conductor. This copper plate is firstly placed on one side. Then the second conductor is put on the other conductor with the copper-plate in between. Secondly, a copper-mesh is wrapped around the connection area. The copper-mesh is electrically conductive and should support the electrical conductivity of the First Aid connector. It is also used to hold the joint with the copper-plate. Lastly, the mentioned insulation sleeve is placed over the connection area and is shrinked down.

During shrinking, the insulation sleeve becomes transparent indicating the right shrinking temperature:

After cooling down, the sleeve turns opaque again and shows that the installation is finished:



With only three components and no special tools needed, the installation of the First Aid connector is indeed very easy and quick. Nevertheless, it serves the purpose as temporary connection for electrical power lines.

Test Results

The following tests are executed on round conductors of overhead lines and sector-shaped aluminum cores of underground cable. The test sequence is not related to any standard by IEC or similar organization. The First Aid connector incorporates a special idea for special application. It is not a standard product to be classified as a joint or a connector etc. with its respective norm.

Following tests are selected to examine the First Aid connector's electrical, mechanical and thermal behavior.

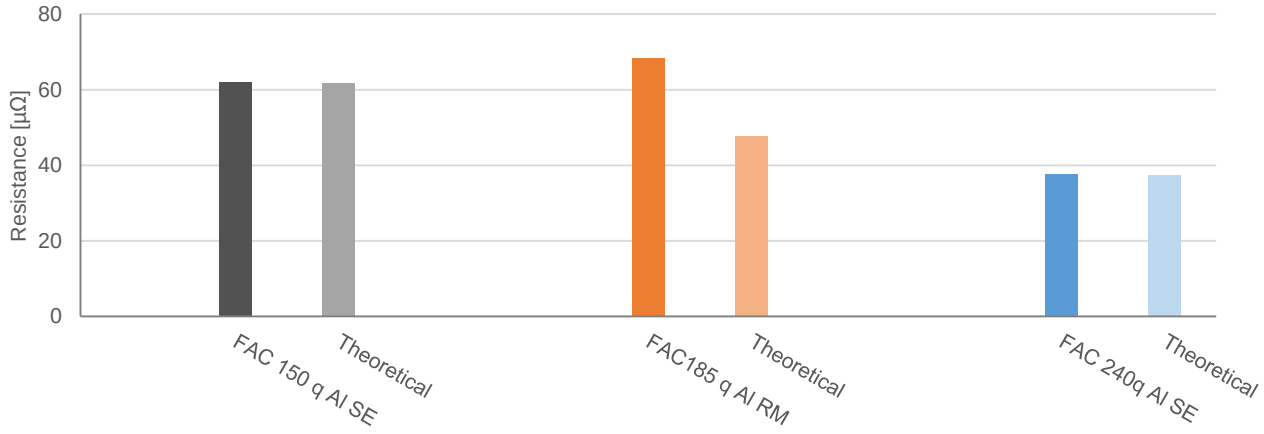
Electrical Property: Resistance

The direct-current-resistance is an important indicator for the electrical performance of the connector. A high resistance would result in high thermal losses at the connector, leading to more heat and higher temperature. The insulation sleeve becomes soft at a temperature of 70°C, which leads to weak mechanical properties. The interface pressure of the sleeve would significantly drop. This would not only affect the electrical performance, but would also limit the mechanical performance dramatically. The mechanical performance is discussed in the next section.

The resistance was measured with a 4-point-measurement at room temperature. A constant DC-current was applied to the samples with a current generator. The current was chosen to 20 ADC. The voltage drop was measured with a multimeter.

The results underline the low resistance values of the First Aid connector independent from cross section. In the diagram, "FAC" is the short form for the Fist-Aid-Connector. "SE" is short for sector-shaped cable conductor, "RM" stands for round overhead line conductor. Both materials are aluminum.
With values not higher than 80 µΩ, the First Aid connector has low resistance similar to metal connectors, even to the bare conductor ("Theoretical" value). The theoretical values are derived from the resistance of an aluminum round conductor of equivalent length by the company Südkabel AG (overhead line AL 1 by Südkabel AG, [Sued-15]).

Thus, the First Aid connector has very good electrical properties and serves the purpose as an electrical connector. But for a connector, there are also other important properties to take into consideration. The next section deals with the mechanical performance of the First Aid connector.



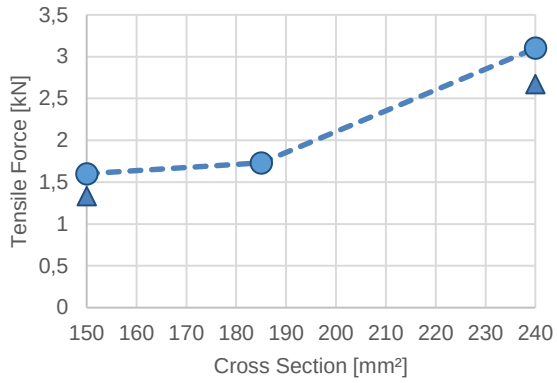
Mechanical Property: Pull-out Force

The mechanical property is especially important for the application as connector for overhead line. As stated by the low resistance values, the mechanical compression force (also recovery force) by the insulation sleeve is high enough to establish a proper mechanical and electrical connection between the cores.

For overhead lines, the mechanical requirements are higher as the two conductors with its respective weight must carried by the connector.
Regarding this requirement, the First Aid connector has been tested and the pull-out force in axial direction of the conductor has been recorded.

The pull-out force, or tensile force allows an estimation of the maximum possible length of the connected overhead line section. For the use as cable joint lying in ground, tensile force is not of interest as the cable do not experience any sag.

Result of the First Aid connector with copper-mesh:

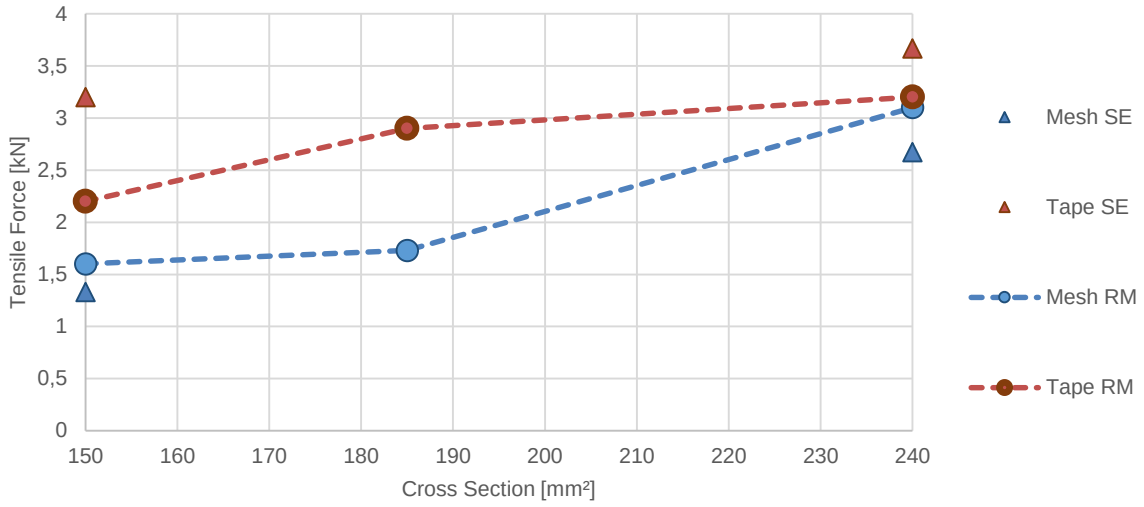


With bigger cross section comes a larger area where the copper plate can dig in the conductor material. With the bigger conductive and connecting area, both electrical and mechanical properties are better.

The design with the copper-mesh was originally intended for a better electrical performance. The development process of the First Aid connector led to another design, which has its strength at mechanical performance with no reduction in electrical function.

Experiments and prototypes with a self-amalgating tape as replacement for the copper-mesh shows that the tensile force is more constant over the whole application range of cross section. Additionally, the mean values for pull-out force is higher.

Result of the First Aid connector with tape in comparison:



The tensile force of the tape design connector is nearly constant over the whole application range. The reason for the better mechanical performance is the soft and rubber material characteristic of the tape. It intensifies the friction between the aluminum conductor and the insulation sleeve. Unlike the copper-mesh design where is less friction between the copper-mesh and surface of insulation sleeve and the conductor. Thus, at the copper-mesh very less friction occurs and the components slip by.

The tape-design has similar low DC-resistance due to the high interface pressure of the insulation sleeve. On the contrary the soft material of the tape has its disadvantage at high temperature and especially load cycling .The better performance of the mesh-design will be presented in the next section

With the forces determined from tensile test, the maximal length of the to-be-connected overhead line can be calculated.

The maximal length is estimated with a model to calculate the maximum sag of an overhead line depending on the distance, the weight of the overhead line and the maximum allowed pulling force.

For the calculation, please refer to the test report of the First Aid connector.

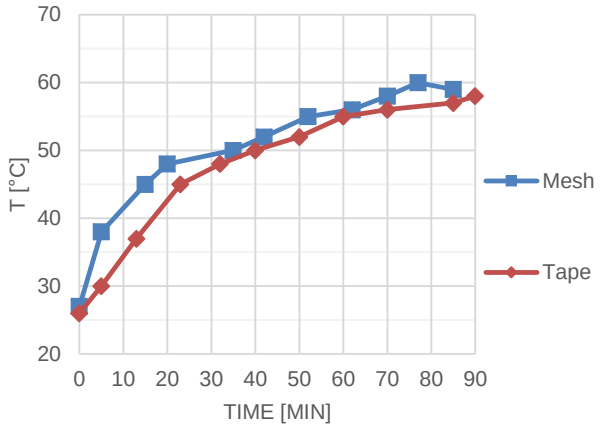
The resulting distances is given in the section “conclusion”.

Operational Behavior

At operation, besides electrical and mechanical stress there is thermal stress for the First Aid connector. To examine its properties at the thermal limit of 60°C, heat cycling has been chosen to simulate operation scenario.

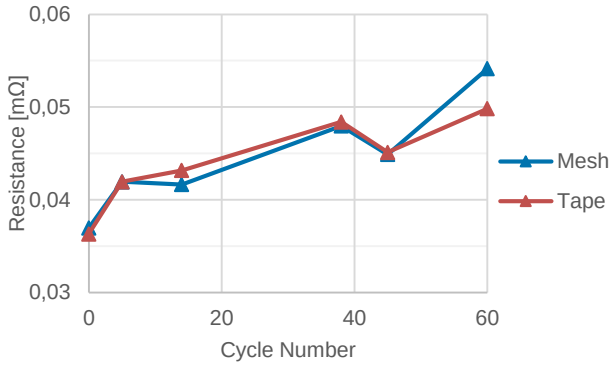
Also, the temperature can be related to the load and loading current. Heat cycling has been carried out on 185 mm² round cores and 240 mm² sector-shaped cores. The heat current is driven by a current transformer with an AC-current. The current transformer is fed by an energy source. With the thermo sensor, the temperature at the connection in a First Aid connector is recorded. The sensor was applied to the connection through a drilled hole on the sleeve.

In total, 60 cycles have been executed. This took a duration of one week. The general temperature curve of one heat cycle is:

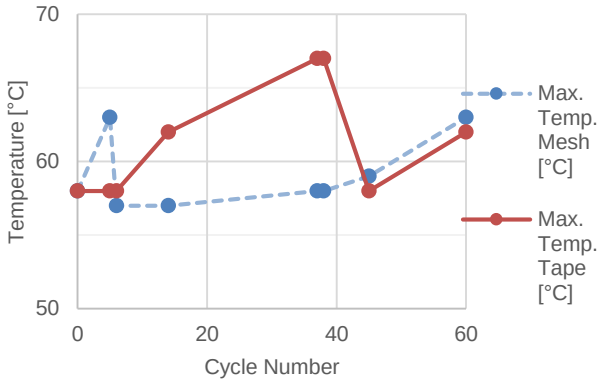


The cooling time is 90 min with natural convection. At specific cycles, the maximum temperature has been recorded.

The chosen heating current is equal to 70 % of full load and as the target temperature of 60°C has been reached in the first heat cycle. In such a way, the First Aid connector can be loaded with maximum 70% of rated current.



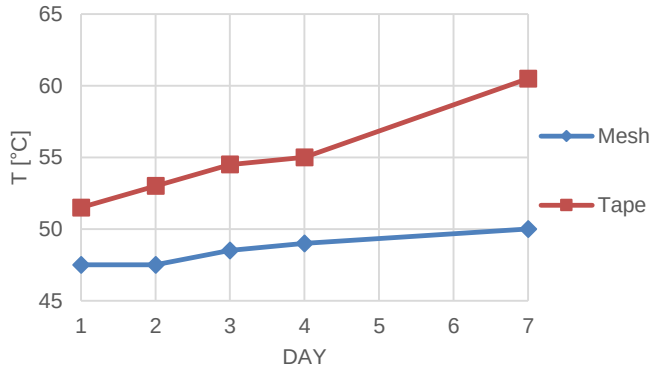
Electrical properties do not limit the performance of the First Aid connector. During the whole heat cycle, the DC-Resistance indicates an ageing process which is underlined by the steeper increase of the temperature. After 30 cycles, the First Aid connector according to tape design hits the limit of 65°C. The current has to be reduced then to 50% of load current.



Now, it is evident that the tape ages faster than the solid copper mesh. During heating up, the tape becomes soft. As the insulation sleeve also loses interface pressure with rising temperature, the recovery force on the connection is lower. During this phase, the resistance is higher resulting in more heat losses. Consequently, the temperature in the connector is rising faster.

The copper-mesh stays solid at operational temperature around 60°C. Consequently, there is no strong rise of the resistance, but only due to ageing of the insulation sleeve.

Additionally, a separate Constant Load test was performed to give further information on the thermal behavior of the First Aid-Connector. During this test, the AC-heating current was continuously passed through the conductor.



Here the temperature rise of the First Aid connector with tape becomes more evident. With the same test setup as current and ambient temperature, the maximum temperature of the tape design is 10 °C higher than the electrically optimized copper-mesh-design.

Thus, the lifetime can be given as maximum 1 week, with equivalent 30 load cycles. The load rating in this scenario is given with 70% of rated current for the respective conductor size. For a lower load rating of 50% the service time is given with 2 weeks.

Summary and Conclusion

- The First Aid connector serves well the purpose as temporary connector for electrical power lines. It has limited thermal and mechanical performance and thus cannot replace a proper connection.
- Within development process, an electrically optimized design as well as a mechanically optimized design is found.
- This mechanically optimized design suits the application of connecting overhead lines.
- Generally, the First Aid connector provides a connection up to 2 weeks, or 30 load cycles.

This results in a covering distance of about 50 m length of overhead line. Detailed covering distances are given in diagrams below.

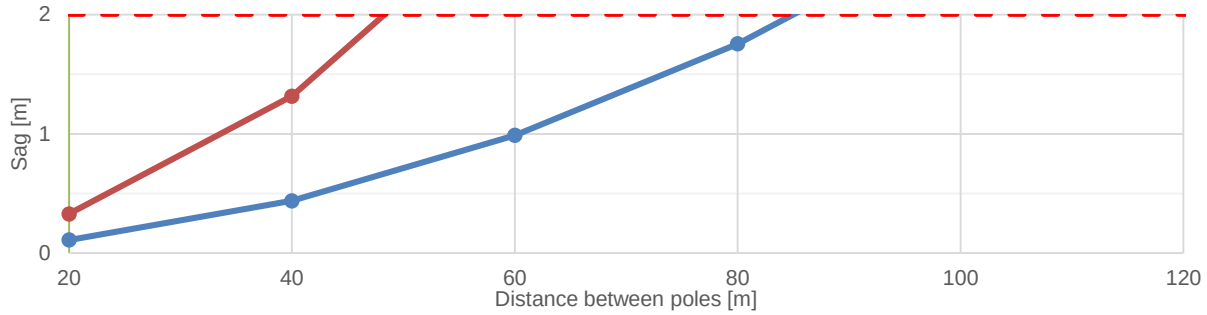
- It can be applied on aluminium conductors with cross-section 150 till 240 mm².
- The current/ load is maximum 70% of rated current or load.
- The use on energy cable is without restriction for the whole cross-section range.
  - For aluminium overhead line, a detailed examination of the mechanical properties gives following results:
  - For cross-section 150 mm² the First Aid connector cannot take the given mechanical load. Therefore, the First Aid connector for 150 mm² conductors, could only be lying on the ground.
  - For 185 and 240 mm², the mechanical limits are given with 3 kN at 20°C and 1 kN at 60°C.

Data	
Application Range	150, 185, 240 mm²
Conductor material	Aluminum
Applicable on	Overhead line, power cable
Load rating & Service time	
70% of rated current	1 week/ 7 days
50% of rated current	2 weeks/ 14 days
Mechanical rating for overhead line – not for 150 mm²	
No load @ 20°c	3 kN
70% of rated current	1 kN
For distances, check diagram on next page.	

For 150 mm²: no mechanical stress, joint has to lay on ground

For 185-240 mm² aluminum conductor:

Red line: 70% electrical load @ 60°C
Blue line: no load @ 20°C
Maximum allowed sag is 2 m on a height up to 10 m



Further Outlook

This application will be further developed. Given by the international patentis an effective and quick to install concept for temporary applications. With new high-performance materials, a more powerful solution can be found.

For the first, test on other insulation tubes sizes will start in order to allow the First Aid connector to cover other cross-sections and applications. Additionally, this application can also be implemented in a cable joint, also replacing metal connectors. In such a joint, every single core could be connected with one First Aid connector.

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WO 2016/012052 A1	International Patent, „Electrical Cable Splice And Method For Connecting Power Cables”, WIPO/ PCT, Publish Date 28.01.2016

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