

# FAILURE ANALYSIS AND EXPERIMENTAL INVESTIGATIONS TO THE JOINT RESISTANCE OF COMPRESSED CONNECTORS IN ALUMINUM CABLES

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**Abstract:** The conventional method for splicing cable uses a hydraulic press to form a compression joint that connects the two ends of a cable is used in many countries using different types of hydraulic compression with different type of compressed tools shape. It is widely used in Egypt due to their simple construction, low cost and easy made, however, the reliability of the structure is quite suspected. Investigation shows that this kind of power connectors needs special treatment during installation and frequent replacement. This work is aimed to analyze the failed compressed connectors being collected from different cities and sites and compared its joint resistance with a new one. It was found that all failed samples have very high connection resistance. Clearly high temperature has been occurred at each connector; Surfaces of most samples preserved obvious melting or welding appearance, some of the sample were even burnt out. Moreover, a calculation model of the long time behavior of electrical joints under high current load is given. And the amount of Energy losses through the joints is calculated.

**Keywords:** Electric joint, Sleeve, Performance factor, Connector degradation

## 1. Introduction

The connector is generally a weak link in the distribution system, which raises serious questions about the ability of some of the connector designs to provide effective long-term connections. Many power connectors in service are subjected to relatively severe outdoor environments. As a result, corrosion is recognized as one of the most significant reliability concerns [1].

There are several factors influencing the performance of an electrical contact. Such important factors are: design, environmental conditions, mechanical and electrical loads,

materials and assembling procedures. As the performance demands on electrical networks and plants in general, and electrical contacts in particular, constantly increases, the need for more reliable rules for design and testing of electrical contacts becomes necessary. As for the design factor, a number of more or less important design parameters can be identified, including: contact force, specific contact pressure (i.e. pressure distribution on the contact surface), contact surface topography (preparation), etc. [2, 3].

Due to the well-known difficulties with aluminum as a contact Material, aluminum connectors have to be carefully de-signed and correctly applied to make a reliable and low-resistance connection. A connector failure in a high-voltage power cable is always accompanied by a dielectric failure of the insulation system [4]. Nevertheless, experience from utilities has indicated that the quality of the various available aluminum compression connectors varies substantially; this impression has been supported through laboratory testing [5, 6].

Cable splices are often considered to be a weak link in underground power distribution systems because they must support the full load in a harsh environment. Failure mainly is caused by the overheating of the connector. The heating of the joint is based on its resistance, which includes contact resistance between strand wires and sleeve, bulk resistance of the sleeve and strand wires as well as contact resistance among individual wires of the strand wire, therefor a research has been done to evaluate the reliability of splices made using the various techniques [7].

The conventional method for splicing cable is widely used in Egypt due to its simple structure, easy installation and low cost. However, investigation shows that this kind of connectors needs frequent replacement. Since high and fluctuated current load and harsh environment in Egypt, there are lots of Problems in application of this kind of connectors. By analyzing the failed connectors that were collected from different cities and sites, high connection resistance of most samples was found. Clearly high temperature has been occurred at each connector. Surfaces of some samples preserved obvious melting or welding appearance, Figure 1.



Figure 1: Melting Sleeve connection.

The above literature shows that a number of factors affect the stability and life of aluminum connectors. The present paper mainly analyzes compressed sleeve Connectors from 11 kV Egypt power systems. These connectors were removed from service due to their unsatisfactory performance under normal operating conditions; furthermore, this paper will introduce the results of the experimental investigations to the initial joint resistance of new compressed Connectors as influence by Preparation of conductor before installation and Sleeve long. In addition, this paper will calculate the long time behavior of the connector using a calculation model and calculate the accumulative energy losses in the connector during their expected working time.

## 2. Sleeve Connector Overview

### 2.1. Definition

A Sleeve connection is accomplished by joining a sleeve to the cable by the compression action of precision dies in hand or hydraulic tools. Hydraulic tools, with their ability to move more metal per crimp cycle, offer faster connector installations. The engineered design of a good joint is a balance between sufficient compression to achieve good electrical performance while not over compressing and mechanically damaging the cable. This is best achieved by a circumferential shaped compression that applies equal force around the sleeve. In this

case, each strand receives an equal amount of compression and carries an equal amount of current loading [8].

## 2.2. Types of Splicing Systems

### 2.2.1. Hand-Built Terminations and Splices

Prior to 1963, hand building was the only way to splice or terminate medium voltage cables. Hand built terminations and splices were a very time consuming process and required workmen having knowledge of what needed to be done. Workmen needed skills in preparing cable and handling tape properly. Most failures occurred because of improper cable preparation or because of improper taping techniques [9].

### 2.2.2. Pre-Molded Splices

Premolded splices consisted of several components which had to be assembled on the cable. Assembly of these devices was somewhat difficult, particularly for the larger cable sizes. Dimensions used in preparing the cable were critical and the inner parts had to be sized to each cable. These could be installed in any environment including direct burial and they were widely used in industry. The biggest cause of failure was improper cable preparation, particularly when related to critical measurements.

### 2.2.3. Shrink-Fitted Terminations and Splices

New Technology in material and stress relief methods appeared in the 1970's and introduced the next major step in the evolution of terminations and splices. Up until the advent of this shrink technology, all stress relief had been accomplished by the geometric method. The development of new material made it possible to accomplish the necessary stress control by capacitive means. The shrink technology provided a distinct advantage to the user. Since devices were manufactured to fit a range of cable sizes. It was no longer necessary to have the exact diameter of the cable insulation for each cable. The shrink technology falls into two classifications, heat shrink and cold shrink [9].

## 3. Experimental Detail

It was well understood that proper installation of the test samples would be essential in order to obtain reliable and representative results. All test samples were, therefore, prepared by experienced jointers from Canal Company for electricity distribution. It was believed that this would guarantee the correct method for sample preparation. The connectors examined were used with 150 mm<sup>2</sup> stranded aluminum conductors.

### 3.1. Sample preparation

For the failed samples, 15 failed cable splice are collected from different regions of Canal Company for Electricity Distribution, Egypt. All of them used sleeve of 10 cm long and had been applied in 150 mm<sup>2</sup> 11 kV underground cable.

For the new one, 30 new samples were prepared by experienced jointers using the same cable by cutting the failed joint and preparing a new one, exactly as happened on the field work. Twenty sample were prepared with 10 cm Sleeve (10 without cleaning the aluminum wire and 10 with cleaning aluminum wire-abrasion and cleaned by alcohol), the remaining 10 cable are prepared by 12 cm long sleeve.

### 3.2. Joint resistance measurement

The joint resistance of this connector includes contact resistance between strand wires and sleeve, bulk resistance of the sleeve, and strand wires as well as contact resistance among individual wires of the strand wire.

Joint resistance of the above collected failed and new sample is evaluated at room temperature, the test points (point A and B shown in Figure 2) were obtained by metallic straps around the conductor at a distance of 25mm apart from two sides of the sleeve connector [10]. A high precision 4-wire micro-ohmmeter with measuring range 10 nΩ- 20 mΩ and a resolution of 1 nΩ, was used for all resistance measurements.

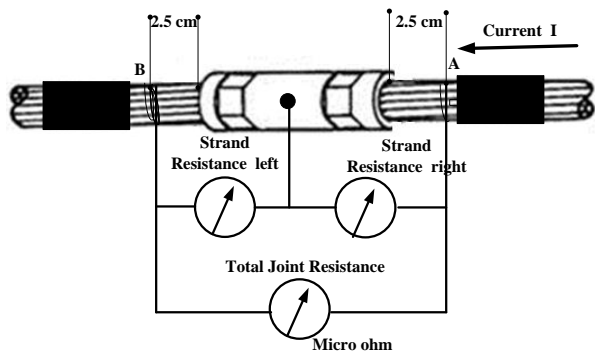


Figure 2 : Experimental Setup

## 4. Experimental Results

The calculated performance factors K -Figure 3- is expressed by Eq. (1) as the ratio of the joint resistance divided by the resistance of an unjointed part of cable of the same length [3, 11].

Performance factor

$$K = \frac{R_j}{R_L} \quad (1)$$

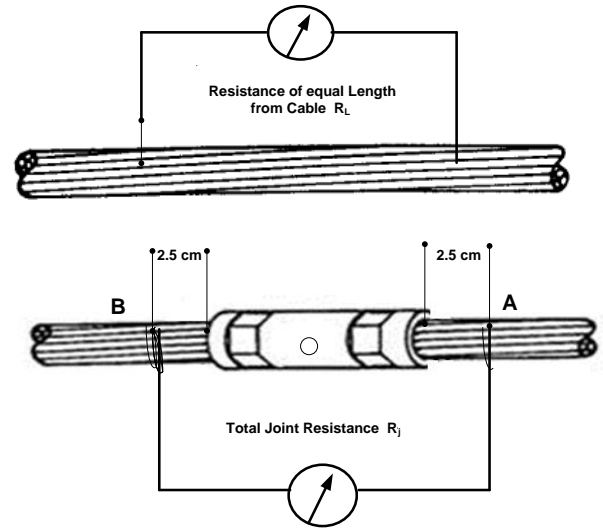


Figure 3: Performance factor Calculation

Table 1 presents the joint resistance for 10 cables of the failed Sleeve, being ranked in ascending order, The table indicate that the failed cable has a very high joint resistance caused by failed splice, As the splice fails, its series resistance increases causing heat to be generated within the splice which must be conducted away by the cable and its jacket, resulting in a localized elevation in cable temperature compared to normal cable. Elevated temperatures increase the deterioration rate of the splice, with a further increase the heat generated. Within a short time, the cable can be hot enough to smoke or flame and to fail completely and catastrophically. Such a failure is clearly undesirable, since it is a serious safety hazard and results in electric power outage until cable repaired or replacement.

Table 2 present the joint Resistance and performance factor (K) for the new connectors The Performance factor is calculated from measured joint resistance values for different cable sleeve long namely 10 and 12 cm , for sleeve long 10 cm the joint resistance was measured for clean (brushed and Solvent cleaned by alcohol) and unclean cable samples. The calculations are repeated for 10 cables from each type. Figure 4 shows the calculated performance factor for all new cables, from this figure it is clear that there is no significant change in performance factor on changing sleeve length from 10 cm to 12 cm, Table 2, points that the calculated average performance factor for unclean 10 cm long sleeve are higher than that of the cleaned one.

Table 1: Joint Resistance and performance factor (K) for the failed connector

Cable Number	Joint Resistance ( $\mu\Omega$ )	K	Cable Number	Joint Resistance ( $\mu\Omega$ )	K
1	170.31	9	6	699.57	36
2	190.25	10	7	870.01	44
3	246.73	13	8	875.65	45
4	518.03	26	9	945.87	48
5	541.43	28	10	1000.67	51

Table 2: Average performance factor for all Samples.

	10 cm Sleeve Unclean	10 cm Sleeve clean	12 cm Sleeve clean
$K_{av}$	0.95	0.77	0.81

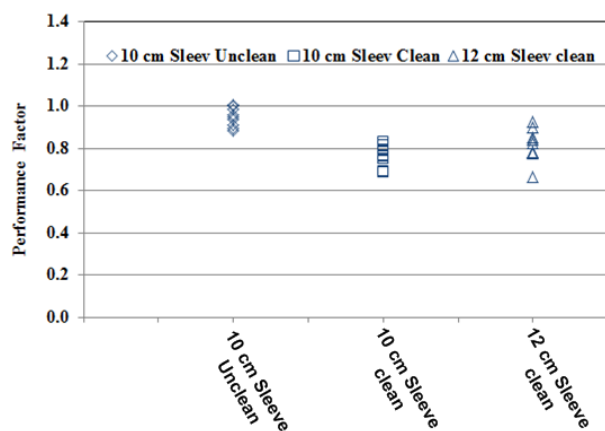


Figure 4: comparison between different sleeve long (clean and unclean).

Figure 5 shows the resistance between each strand and the sleeve, which can serve as a suitable indication of how the injection current is distributed in the outer layer of the cable. The latter is an indication of how good is the contact between the strand and the sleeve. It is clear that when the cables are cleaned before installation the measured resistance is smaller than that without clean for all strands, moreover the measured resistance for cleaned cables are approximately equal for all strand in the left and right side which mean normal

distribution of the current. On the contrary, unclean cable appears to have high resistance for all strands and unequal value for all strands, these unequal values substantially, indicating a very non-uniform current distribution among the stranded wires.

Unequal current distribution causes high temperature area, i.e. hotspot, in the Joint. This has led to the accelerated aging and degradation of splice connectors, which cause increasing in joint resistance. Significant increase in splice connector resistance cause significant reduction in the joint strength, which could ultimately result in separation of the cable joint and can lead to breakdown of the connection over time. This may be the main reason for frequently failure of this type of connector in Egypt, the jointer always don't clean the cable or sleeve before formation the joint, This results in a joint containing a set of impurities such as dust and small aluminum particle from cutting the cable to do the joint ..etc.

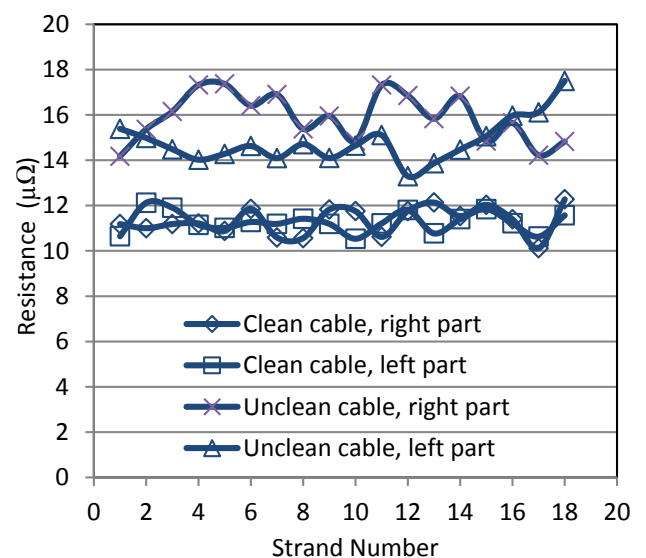
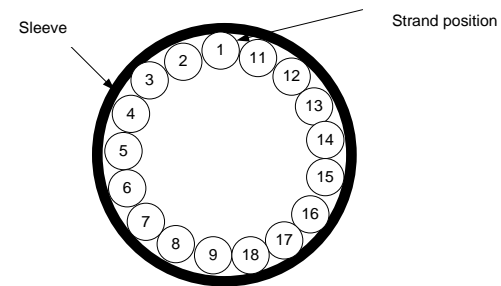


Figure 5: Strand resistance for clean and unclean cable

Previous work show that dust particles cause electric contact failures which seriously influence the reliability of the electric systems. Therefore, a layer of dust which can cover the surface should be prevented. The mixture of dust particles and wax could be very harmful to the contact, especially under low normal force; furthermore, experimental result showed that electric contact failure is closely related to the particle size and the morphology of the contact surface. Theoretical analysis indicates that there is a hazardous size range of the dust particles within which dust particles are difficult to be moved away from the contact and thus causes the contact failure [12, 13].

### 5. Long Time Behavior Calculation:

Long-term tests on over 400 busbar joints with different materials, current-loadings and environmental conditions (transformer oil, indoor and outdoor air) have been carried out. Based on the results of these tests and theoretical investigations a mathematical model, equation (1), which describes the chemical/ inter-diffusion ageing process depending on the conductor material, the connection design, the assembly quality and the loading has been developed [14, 15].

$$K(t) = (K(t) - K_I) \frac{d e^{-\left[\frac{b}{R T_C} + \frac{1}{2}\right]}}{\left(\frac{t}{t_0}\right)^m t_0} \quad (2)$$

The parameters for Aluminum-to-Aluminum joints  $m = 0.487$ ,  $b = 9709 \text{ J/mol}$  and  $d = 0.1$  are determined from long term tests for a variety of joints [15].

The alteration in the performance factor of bolted joints depends on the temperature  $T_C$ , the ideal performance factor  $K_I$ , the initial performance factor  $K(0)$  and time  $t$ . The value of  $K_I$  (Ideal Performance factor) is calculated using the data sheet for the cable and sleeve dimension.

The average lifetime of a joint in electric power systems is not interesting from a reliability standpoint, but the lifetime of the joint which fails first is very important.

Figure 6 allocates the progress in the performance factor for compressed connector with sleeve 10 cm length (clean and unclean) and 12 cm length sleeve, from the figure it is clear that the clean 10 cm Joint have the highest live time and the lowest live time are fore 10 cm unclean sleeve. The figure indicate that cleaning the joint can increase the joint live time by about 10 years.

Assuming a very good installation for the compressed joint and the same Ideal performance factor and working operation, decreasing initial performance factor from 1 to 0.6 increasing the live time for the joint by more than 20 year, this can be conclude from Figure 7.

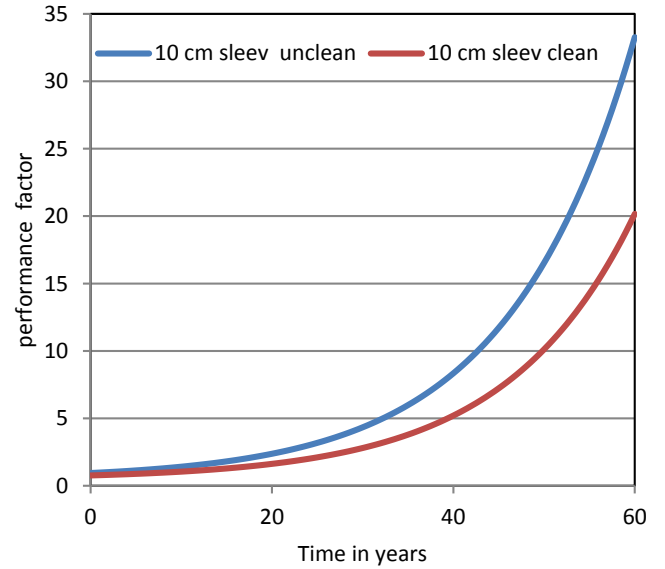


Figure 6: Long term behavior for the under test compressed connector.

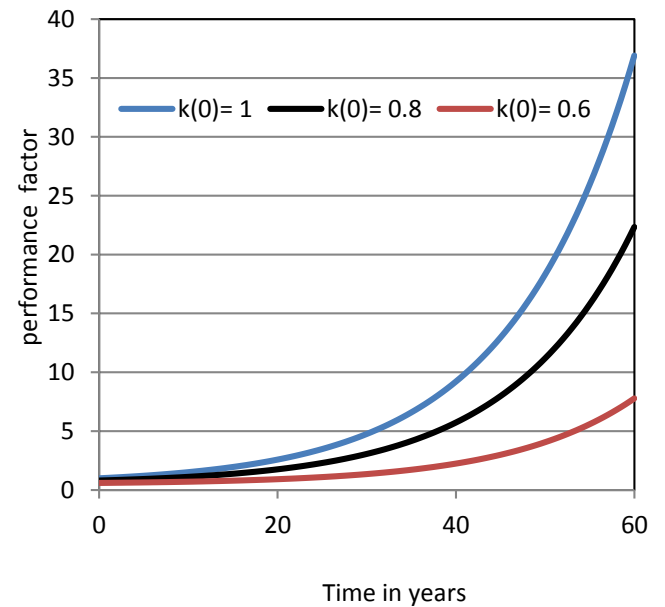


Figure 7: Performance factor of the under test compressed connector

## 6. Power Dissipation Through Electric Joint

The energy losses through the compressed connector was calculated for the new connector taking the average joint resistance- Table 2- of all joint resistance for each type as base in calculation.

Figure 8 shows typical results of the relation between energy losses and different loaded current of the new joints for a time of 1 year. From this figure, it can be seen that the Energy losses through the unclean joint is higher in comparison to the clean joint. Moreover, the energy loses through the clean joints with sleeve 10 cm and 12 cm are approximately the same.

Figure 9 shows The cumulative wasted energy loss in Kilowatt-hours over a live time of 30 year depending on the result obtained from Figure 7 and assuming that the cable are loaded by its rated current 250 A, from this figure it is clear that a large amount of energy can be saved by good installation to the joint to have minimum permissible initial joint resistance.

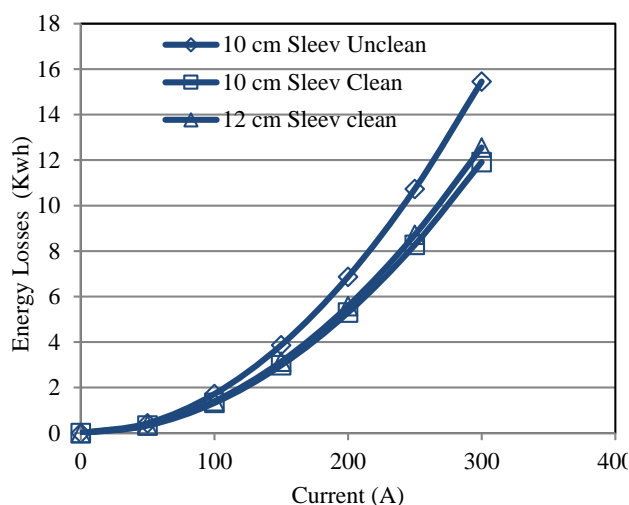


Figure 8: Energy Losses for one joint in one year.

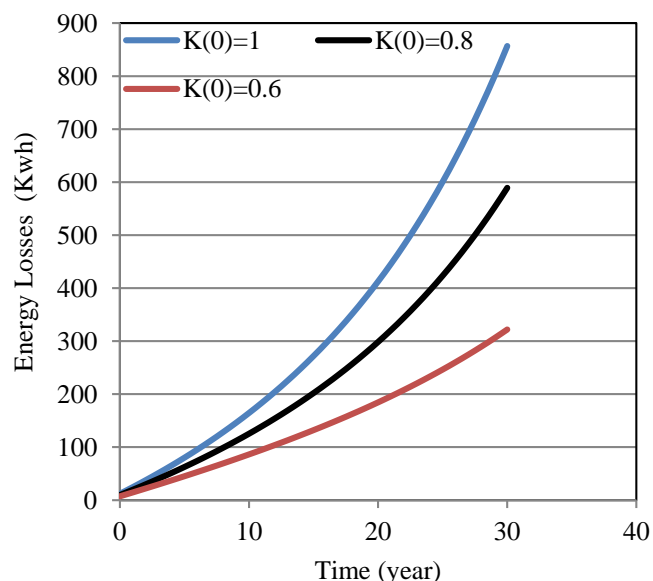


Figure 9: accumulative Energy Losses in compressed connector.

## 7. Conclusion

- 1- Surfaces of most failed samples preserved obvious melting or welding appearance, indicating that they were subjected to very high temperature during normal operation causing from very high joint resistance.
- 2- From the experimental tests, compressed connector in aluminum cable hasn't significant affected by changing sleeve length.
- 3- Comparing results of clean and unclean joint resistance measurements show clearly that the joint resistance of compressed connectors can be significantly decreased by surface preparation, and causes good connection between strand and sleeve for the outer layer, which prevent hot spot on the joint.
- 4- The structure of compressed joint that connects the two ends of a cable is very simple with comparatively low cost. However, it is necessary to estimate the overall cost of application of such connectors including maintenance fee, frequent replacement of connectors, energy loss due to high connection resistance etc. these costs give The true cost of electrical connectors.

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