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A Consequence of Failure of Mid Span Compression Joint on the Kelanitissa-Kolonnawa Line

J. Rohan Lucas and Nanda Munasinghe

Abstract: Mid-span compression joints in overhead transmission line conductors need to give not only reliability, but also electrical and mechanical properties equivalent to the original conductor. The use of an inappropriate joint can lead to disastrous consequences. An example of this is the complete blackout of the Sri Lankan power system in October 2009 through the use of an inadequate size joint. This paper is based on investigations which revealed that the initiating cause of the blackout, was the failure of a previously replaced inadequate mid-span straight-through joint between ZEBRA and ZTACIR conductors. Inadequate line protection allowed it to progress to a complete blackout. A detailed analysis of the failure is presented and provides information to avoid such occurrences in the future.

Keywords: Overhead line conductor, Straight-through compression joint, Conductor failure, Corrosion, Blackout

1. Introduction

Mid-span compression joints are used in overhead transmission lines to connect line conductors together, in-between high voltage towers. These compression joints are required to give not only reliability, but also mechanical and electrical properties even superior to the original conductor. The use of wrong joints can have dire consequences, as was experienced on 9th October 2009, when an all-island blackout occurred in the Kelnitissa-Kolonnawa (KEL-KOL) line of the Sri Lankan power system commencing just after midnight. As it was deep into the night, what was immediately detected was that a fire had erupted at Kelanitissa substation which had been reported to the System Control Centre of the Ceylon Electricity Board. It was subsequently ascertained that the blackout had been initiated by a conductor of the 132 kV KEL-KOL line falling and creating a heavy short circuit current, leading to the fire [1].

Figure 1 - Location of the Conductor Failure Showing the Failed/Ruptured Conductor [1]

Photograph has been taken when the tower-side section of the broken R-phase conductor still remained entangled with the tower, touching the Y and B conductors as well.

2. Key Events that Triggered the Blackout

Investigations reveal that in the early hours of the morning, the R-phase conductor of a KEL-KOL circuit fell on the ground, inside the Kelanitissa substation [1]. The R-phase conductor had sheared at the edge of a straight-through joint that existed in the section between the terminal tower and the line gantry at the KEL end. This resulted in breaking the R-phase conductor in mid span into two parts, with one part falling on the ground creating an earth fault.

Eng. (Prof.) J. Rohan Lucas, C. Eng., HLFIE(SL), FIEE, B.Sc.Eng. (Hons) (Cey), MSc (Manch), PhD (Manch), Senior Professor, Department of Electrical, Electronics and Telecommunication Engineering, General Sir John Kothelawala Defence University, Emeritus Professor, Department of Electrical Engineering, University of Moratuwa.
Email:lucas@kdu.ac.lk
https://orcid.org/0000-0001-7215-0815
Eng.(Dr.) Nanda Munasinghe, MIE(SL), MSc (Berlin), PhD (Berlin), Retired Professor, Department of Materials Science & Engineering, University of Moratuwa
Email:nandamunasinghe@gmail.com
https://orcid.org/0000-0001-7861-0181

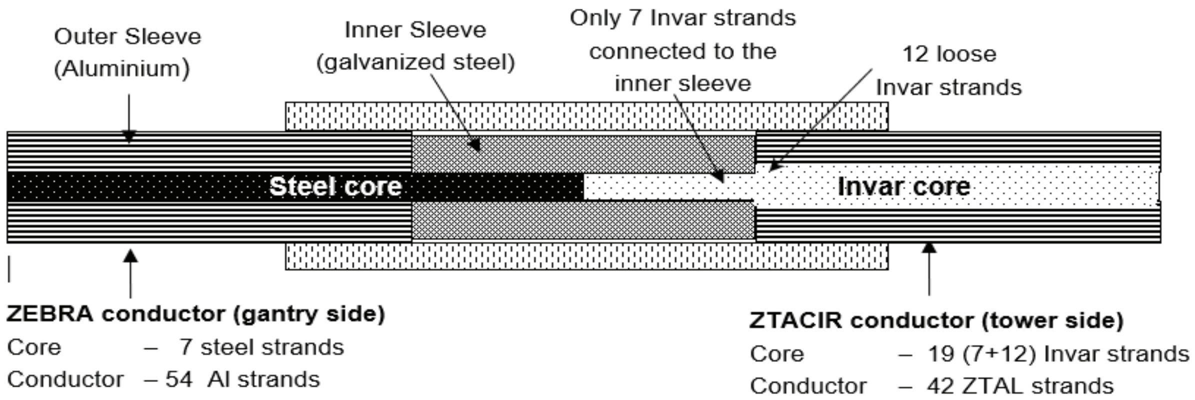

Figure 2 - Schematic Diagram of Failed Mid Span Compression Joint [1]

The other part of the R-phase conductor, still hanging on the insulators attached to the terminal tower, had got entangled with the crossarms of the terminal tower, simultaneously touching the other two conductors (Y and B phases) of the same circuit (Figure 1).

With the R phase conductor on the ground, it created a line-to-ground fault. Investigation shows that in less than one second, the other two conductors (phase Y and phase B) were in contact with the ground through the tower.

Thus, the initial R-phase to ground fault had rapidly developed into a full-scale three-phase to ground fault. With all the three wires of the KEL-KOL circuit in contact with the ground, dangerously large currents flowed to the ground. This resulted in the fire that had been reported to the Kelanitissa substation staff. Protection systems installed should have automatically tripped the faulty line and isolated it from the system in less than 100ms. However, backup protection at the Kelanitissa end, as well as the differential protection which had been especially installed did not operate [1].

3. Reasons for Failure of the Joint

The authors were entrusted by the investigating committee to study and report [1] on the failure of the joint.

3.1. Description of the Conductor

The conductor on the KEL-KOL line is of type 'ZTACIR' with an inner 'Invar' core (with 19 strands) and two outer layers of conducting strands of thermally resistant aluminium with Zirconium 'ZTAL' (with 42 strands) – stranding details observed from undamaged section of ZTACIR conductor. ZTACIR is especially used to reduce the sag in transmission lines when a higher current carrying capacity is required [2].
The joint that failed was a straight-through joint (Figure 2) between ZEBRA (Steel reinforced Aluminium conductor) and ZTACIR (Invar steel reinforced Zirconium alloy Aluminium Conductor) conductors (Figure 3), done in the year 2006 with accessories meant for a ZEBRA-ZEBRA joint as a temporary measure. Unfortunately, the joint had not been rectified.

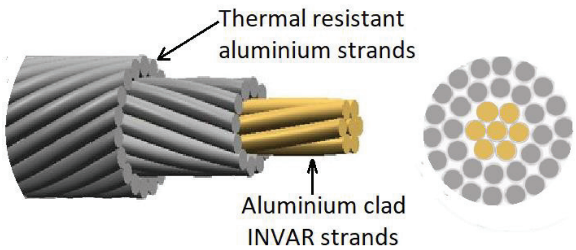

Figure 3 - Structure of ZTACIR Conductor [2]

The ZEBRA jointing sleeves do not fully fit the ZTACIR conductor and has left 12 out of the 19 core strands outside the inner sleeve of the joint during jointing (Figure 2).

Further, owing to inappropriate sleeves, severe arcing has caused the ZTACIR conductor strands to evaporate, until the joint finally failed on 9th October 2009. Severe corrosion was subsequently observed around the failed joint and its sleeves.

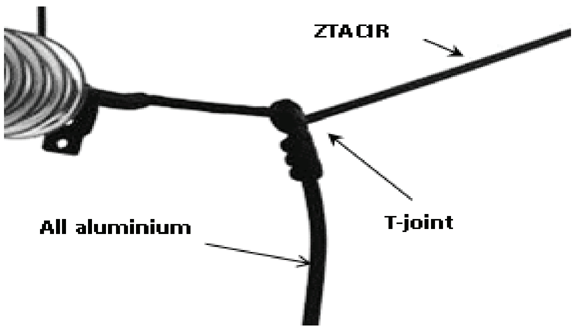

Figure 4 - A T-Joint Similar to the one that was Mechanically Stressed [1]

3.2. First Rupture of the T-joint

Earlier, in 2006, a T-joint to tap the ZTACIR down conductor of the R-phase of circuit No. 2 of the transmission line, ruptured. The T-joint taps the down conductor (Figure 4), and serves power to an all-aluminium conductor, which is connected to the switchyard.

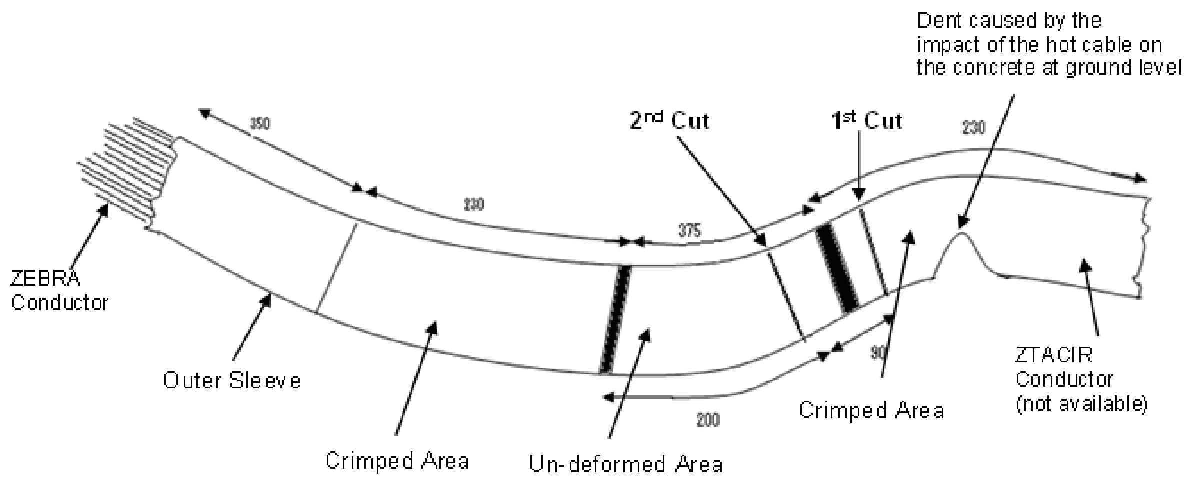

Figure 5 - Damaged Mid-Span Compression Joint made Available to the Study Team [1]

Investigations revealed that the T-joint used between 2004-2006 on the ZTACIR conductor was a T-joint normally used for ZEBRA conductors [3]. This ad-hoc measure had been required because no special ZTACIR T-joint spares were available, although this was a line newly built in 2004. It was noted that frequent tightening of the T-joint was required once in a few months, and hot spots were frequently detected on the T-joints. Similar T-joints were fixed in all the other five conductors on this line, and they have been in service throughout 2004 to date, but with constant care by maintenance staff. In addition, owing to the short distance between the tower (where the three conductors are in a vertical plane) and the gantry (where the conductors are in a horizontal plane), higher mechanical stress would have developed in the conductor. This is because of the sharp angle between the main conductor and down dropper at the gantry as seen from Figure 6. The terminal tower is partly visible on the right-hand side. R-phase is the closest to be seen in the picture. The conductor rising from the gantry to the tower snapped and fell on the ground.

Figure 6 - Conductor Arrangement (Tower to Gantry) of KEL-KOL Lines [1]

Further, the T-joint designed to tap a horizontal conductor was now being used on a conductor with a sharp incline. It would have collected water from the top end owing to the high slope of the conductor from the terminal tower to the gantry. This would have probably led to the increased level of corrosion visible in the sample and is a possible reason for the fracture of the conductor at the T-joint in 2006. As a remedial measure, a section of the ZTACIR conductor between the gantry and the terminal tower was replaced with a ZEBRA conductor. This ZEBRA conductor had been connected to the ZTACIR conductor with a mid-span compression joint.

Owing to the non-availability of the correct material and tools to make a mid-span joint connecting the ZTACIR conductor on the line-side with the Zebra conductor on the gantry-side, jointing material designed for the ZEBRA conductor had been used. After being in operation for approximately three years, this mid-span joint failed on 9th October 2009 and dropped to the ground, leading to the grid failure.

4. Analysis of the Failed Joint

The main part of the damaged mid-span conductor joint available for the study team, is illustrated diagrammatically in Figure 5. A ZEBRA conductor (on the left-hand side) has been connected to the ZTACIR conductor (on the right-hand side) with a steel inner sleeve and an aluminium outer sleeve.

Figure 5 shows sectioning at two locations (1st cut and 2nd cut) to examine the condition of the joint. The entry of the undamaged ZEBRA conductor to the mid-span joint is on the left-hand side, while on the right hand side, where the ZTACIR conductor was fixed, the whole conductor has been completely burnt and the strands have become detached from the outer sleeve. However, some burnt conductor parts were found stuck inside the outer sleeve.

This is the last segment of the line at KEL end. The ZEBRA conductor was hanging from the insulator string on the gantry, and the section shown in this diagram hit a concrete structure at ground level. Severe ground fault current would have flown in the section during the 3-second period. The cuts were made by the team during investigations.

The strands had melted and some spatter was also observed on the inner surface of the outer sleeve, as seen in Figure 7.

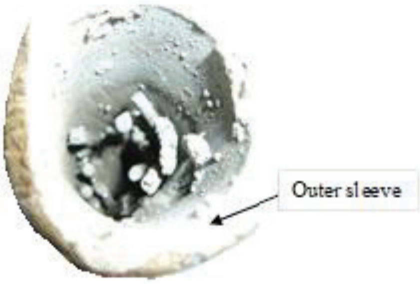

Figure 7 - Burnt Strands in the Outer Sleeve on the TACIR Conductor Fixing Side [1]

This indicates a very high increase of the temperature, possibly due to high contact resistance between the conductor strands and the outer sleeve.

The conductor was cut initially in the crimped area (see the position of the 1st cut in Figure 5) and it was found that the core strands were separated from the inner sleeve and also the ZTAL strands of the ZTACIR conductor were removed from that area. No conductor strands were observed between inner and outer sleeves. The damaged mid-span joint was further cut (see the 2nd cut shown in Figure 5) and a part of the inner sleeve was taken out from the outer sleeve, where it was found that the inner core wires from the ZTACIR conductor were detached and the fracture surface was indicating some corrosion.

Figure 8 - Inner Sleeve Observed at 1st Cut from ZTACIR Conductor Side [1]

It was also observed that only 7 stands of the 19 strand Invar core of the ZTACIR conductor were fixed inside the inner sleeve. This is because the joint had been made with sleeves meant for the Zebra conductor, in which the inner steel sleeve can accept only the 7 steel strands of the ZEBRA conductor (Figure 8).

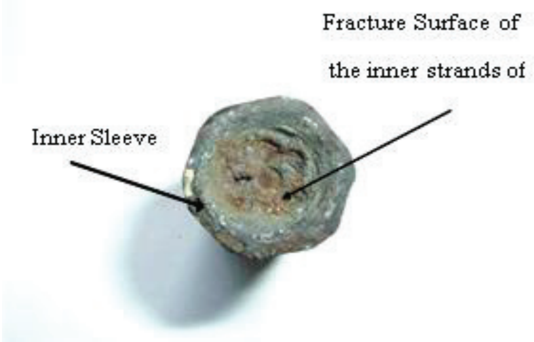

Figure 9 - Fracture Surface of the Steel Strands of the Inner Sleeve, at the 1st Cut [1]

On the other side of the inner sleeve (at the 2nd cut), it was clearly visible that there were 7 Invar (core) strands which were properly fixed and not damaged (Figure 10). Since the Invar strands in the ZTACIR conductor has less strength than the corresponding steel strands in the ZEBRA conductor, using only 7 strands of the 19 available strands would definitely have made the connection to be of inadequate strength.

Figure 10 - The Inner Sleeve with 7 Invar Core Strands at the 2nd Cut [1]

Furthermore, severe corrosion was also observed on the outer side of the inner sleeve. It was not clear whether the corrosion has taken place before or after the heat increase (Figure 11).

Figure 11 - Severe Corrosion on the Surface of the Inner Sleeve [1]

The balance 12 Invar strands of the ZTACIR conductor were free and only fixed by the outer sleeve. This may have caused a premature fracture of the core and caused the detachment of the current carrying aluminium strands from the outer sleeve. In this process, severe sparks may have been created and temperature would have increased to a level adequate to melt the aluminium strands. The fracture between the 7 Invar strands and the inner sleeve might have been accelerated by severe corrosion of the inner sleeve and mechanical stresses [4].

5. Transmission System Maintenance

Investigation has shown that transmission maintenance is being carried out under extremely trying circumstances. The grid, although designed with n-1 reliability, at most times, such reliability standards have to be sacrificed during operation due to financial considerations.

For example, when sufficient water is available and spilling is a possibility, ignoring all reliability standards, certain transmission lines are loaded to near thermal capacities. In these situations, tripping of one of these highly loaded lines could lead to a total or partial grid failure.

In such a situation, releasing transmission lines for maintenance work becomes virtually impossible and as a result, maintenance programs are either postponed or hurriedly done, thus totally disrupting the planned maintenance programs. This affects system reliability in no small way.

Developing professional expertise in these fields, for that matter in any field in electrical engineering, needs long years of experience, commitment, ability, sound understanding of the fundamentals and a continuous knowledge transfer. Once CEB develops such expertise, a path should be opened to transfer this knowledge and experience to others, and also to retain such professionals in the respective Divisions. This seems to be lacking to some extent.

6. Conclusions

The study carried out on the failure of an inappropriate mid-span joint between ZEBRA and ZTACIR conductors led to a drastic all-island blackout. Incidents of this could be prevented by due care as follows.

Mid-span compression joints between different conductors should only be done with utmost care, and only using the appropriate tools and accessories [5]. In an exigency, in the absence of fully appropriate accessories, joints made should be only a temporary measure with regular checks being made until rectification as soon as possible.

It is to be noted that material and mechanical properties of the sleeve as well as conductors should be compatible with each other, and the crimping tool should match with the joints and the conductors involved.

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