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A multidiscipline 35 kV cable failure investigation

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Cable failure investigations must evaluate all facets of cable technology to reach a complete understanding of why and how a cable failed. This paper presents the salient points of a recent investigation into an in-service failure after only several weeks of operation.

A 35 kV, 500 mm² (1000 kcmil) cross linked polyethylene, copper tape shield, PVC sheathed power cable feeding a new dc arc furnace at a Mexican industrial plant failed shortly after energization. The investigation followed a preliminary work plan and schedule that included a detailed analysis of cable manufacturing, cable installation, operation methods, failure events, power system topography, operation and protection. The work plan provided laboratory analysis to support all studies and conclusions. On site evaluation at the installations of the cable manufacture and the industrial plant was carried out and a brief summary of the technical background is submitted in this paper.

As part of the investigations into the failure of the cables, it was required to carry out a study to determine if overvoltages in the industrial distribution network could have been a contributory factor to the failure of the cables. An EMTP (Electro Magnetic Transient Program) study was performed simulating the 35 kV distribution network in detail, including harmonic filters and the step down transformers to the converters. Circuit breaker operations were simulated, and the effect of filters and possible harmonic resonance in the distribution network was examined. The results did not show any overvoltages that would endanger the insulation of the cables. Maximum overvoltages occurred during line-to-ground faults, which caused the sound phase voltages to increase to about the phase-to-phase voltage. This is normal and to be expected in similar systems and should not result in insulation failure. A maximum transient overvoltage found from the simulation was 65 kV peak which compares with the cable power frequency voltage withstand capability of 98 kV peak. The 35 kV system exhibited a natural resonant frequency between 120 and 180 Hz. Due the type of filters installed this is not likely to cause linear or ferro resonance. In conclusion, it is believed that dielectric stresses across the cable insulation did not contribute to the cable failures.

A review of protective relay operations as part of the failure investigation verified that during the cable failure all protective relays correctly operated. Lower magnitude (911 amp to 1,250 amp) cable faults were each time selectively detected and cleared by appropriate protective relay operations. A high magnitude (14,700 amp) fault was also appropriately cleared by instantaneous relay operations, but in this case selective clearing was not possible. Therefore it can be concluded that protection operation during the cable faults was satisfactory.

The metallurgical investigation was carried out in three phases. The first part assessed the copper tapes taken from the failed cable and the new (unused) copper tapes collected from the manufacturer's plant. The second part assessed the integrity of the copper tapes taken from a spare cable (10 metre sample subjected to electrical tests) and the third part simulated the cable installation.

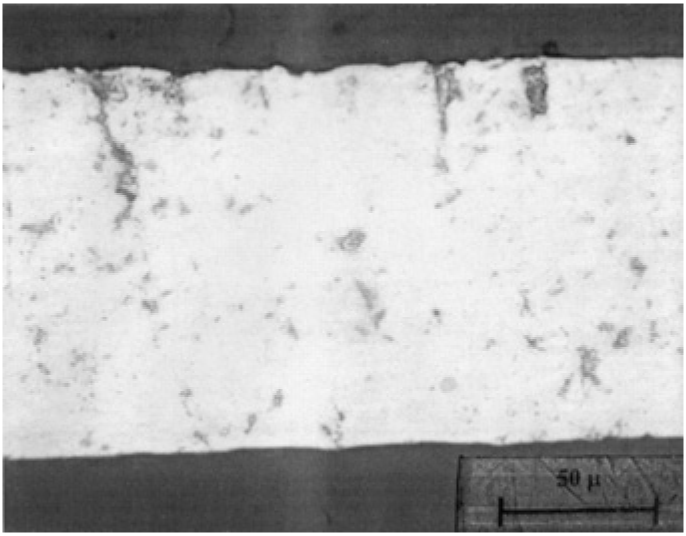

Figure 1: Microstructure of the edge of copper tape sample showing tramp elements and oxide inclusions. (Mag. 500X)

Based on the findings of this investigation, the following conclusions were drawn:

- Tramp elements and oxide inclusions appeared at localized areas along the edge of the copper tape of the failed cable (Figure 1). These defects reduced the tape's tensile strength and elongation.
- Bending and pulling the cable through a sharp radius can easily wrinkle the copper tape of the failed cable. Certain parts of the cable can be exposed to an excess of 3000 lbs of load when the cable catches around the sharp bend. When the edge of

the copper tape that contains the defect is caught in this way, the copper tape will fracture due to mechanical overload.

Hence, it is concluded that the fracture of the copper tape of the cable took place due to a combination of the defect on its edge and an abnormal bending operation. It appears that these two factors individually would not fracture the copper tape.

The cable failure investigation examined all possible causes of the failure. As a result of electrical system studies, protection and control evaluation and numerous laboratory testing programs the following conclusions can be given:

1. The electrical system study did not show any overvoltages of sufficient magnitude to damage the cable insulation.
2. Review of the protective relay operations verified that during the cable failure all protective relays operated correctly.
3. The cable failure was probably caused by a combination of two problems. The first and most damaging, was the over-tensioning and mishandling of the cables during the installation. And the second problem was the presence of tramp elements in the copper tapes left during manufacture of the tapes.
4. Once the copper tape shield separated into sections during installation, each ungrounded portion experienced a voltage through capacitive coupling leading to sparking across the resultant gap in the copper tape, rapidly eroding the semiconductive insulation shield and finally the cable insulation.

Footnotes:

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