Power Cable Failures

Introduction

Almost all utilities and large industrial facilities have extensive systems of power cables. Many of these cable systems are ageing and failures are becoming common. Finding the root cause of cable failures can lead to better maintenance practices and produce more reliable operation in the future. This in turn will lead to lower operating costs. As an example, the final result of a cable failure may be that the insulation failed and the cable flashed over. The root cause may in fact be a building contractor removing thermally conducting back-fill around the ducts thereby causing local overheating. Determining the root cause of the failure can help prevent future failures. Root cause analysis requires a systems approach.

Power Cable Systems

One of the fundamental aspects of the cable system is the method of installation. Cable systems can be installed in various ways including:

- In trays or troughs, either in- or out-doors
- Suspended from poles, bridges, or walls of vaults or tunnels
- Buried in ducts or conduits, or direct buried
- Underwater as a submarine cable
- In special situations as mine trailing cables, crane cable etc.

Always keep in mind the installation when looking for the cause of a failure. Cable accessories are often the most prone to failure of any part of the cable system. Accessories include terminations and joints, also called splices. Terminations are required to connect the conductor of the cable to a bus or other cable conductor. Within the termination the cable’s metallic and semiconducting shields must also be properly terminated. Splices may be simply considered two terminations, connected back to back.

Another aspect of the cable system is the operating environment. Some points of the operating environment, which must be considered, are:

- Cable current loading compared to cable ampacity
- Ambient temperature
- Type of backfill around direct buried cables or ducts
- Moisture or chemicals in contact with the cables and accessories
- Lightning impulses and other system induced over-voltages

- Switching operations.

Final results of a Failure

A cable failure almost always exhibits itself as either an open circuit or a short circuit. Open circuits are more common in low voltage cables than at medium or high voltage. Open circuits are usually the result of failed connectors, or broken and/or corroded conductors. The reason that open circuit failures are rare in higher voltage systems is that arcing will occur in the conduction path, leading to overheating, failure of the insulation and a short circuit. Short circuit failures will most often cause the protection system to operate and interrupt the current flow to the load. There are times when the flash over at the fault may result in more serious consequences like fire or even explosion.

Root Cause Failure Analysis

Root cause failure analysis is the process of examining a failed sample, along with the operating and environmental information, to determine the fundamental cause of the failure. During the failure analysis, various tests may be conducted on the failed sample, on pieces of nearby unfaulted cable, or on accessories removed from adjacent un-failed phases. Each bit of evidence is looked at as an effect, which had a cause. Then each cause is looked at in turn as the possible effect of a previous cause. This cause/effect trail is followed to the fundamental or root cause. The amount of evidence that can be gathered will depend on the condition of the sample, what has happened to the sample since the failure, and the availability of information about the failure and previous conditions that the cable or accessory has undergone. Often direct evidence at the failure site is destroyed by the fault. An important factor in failure analysis is of course the amount of time and money one can spend on the analysis.

Two important things that must be done in any failure analysis are a close visual examination of the sample at and near the failure site, and talking to or reading accounts of the failure from the personnel involved. Depending on the circumstances more investigations or tests may be required, or more information may be requested from the cable user.

If the failure occurred in a polymeric cable, other work may include:

- More detailed examination of the conductor including possible metallurgical examination
- Dissecting the insulation close to the failure and cutting wafers
- Measuring insulation resistance
- Performing ac breakdown level tests on a long sample near the failure site
- Performing chemical tests on the insulation
- Measuring semicon resistivity at elevated temperature near the failure site
- Performing metallurgical tests on the shield or sheath if present
- Performing chemical tests on the jacket if present

Cracking of embrittled insulation

During the examination, look for signs of overheating. These may include discolored metal, or cracked and distorted polymers. **Figure 1** shows an embrittled and cracked polyethylene wafer caused by overheating. Remember to look at samples sufficiently far from the fault site to be sure they were not damaged by the arcing fault. Overheating may indicate a possible root cause of failure of the system protection, incorrect determination of the system ampacity, thermal runaway, or lack of thermal backfill. Signs of over heating may warrant further chemical or metallurgical tests to determine the maximum temperature reached. Further investigation into system operations may be necessary to determine the true root cause of this type of failure. Examples of root causes of over heating may be poor initial ampacity calculations, improper breaker settings, removal of proper backfill, or change in ambient conditions like the adding of a steam pipe.

Cable wafer with extensive voids

Voids or inclusions in the insulation, or protrusions from the semicon may be seen in the wafer examination. **Figure 2** shows a cable wafer with extensive voids. Voids are simply bubbles in the insulation, while inclusions are foreign matter. Protrusions are sharp points extending into the insulation from the semicon. These are all forms of cable manufacturing defects. All cause high local electrical fields, which may lead to partial discharge at the site or rapid growth of water or electrical trees near the defect. Any of these observations indicate a manufacturing defect as the cause of failure. Unfortunately the defect, which may have caused the failure, is usually destroyed by the fault, but the presence of nearby defects may give sufficient evidence of poor manufacturing. Since modern cables can be produced with super-clean insulation and semicons, and very few defects, one might conclude that the root cause of these types of failures occurring in newly purchased cables is poor specifications or acceptance testing.

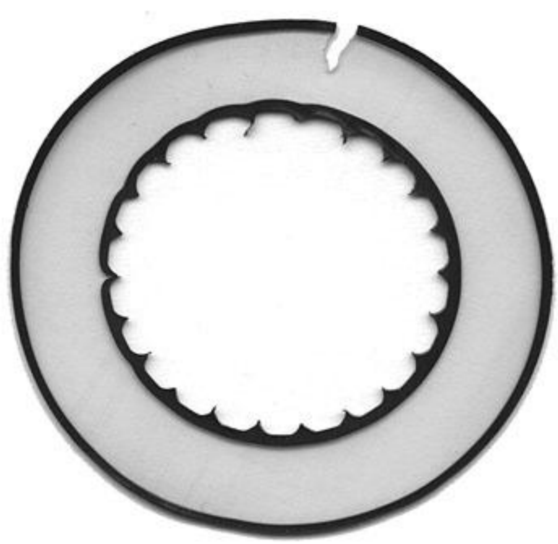

Figure 1. Cracking of embrittled insulation

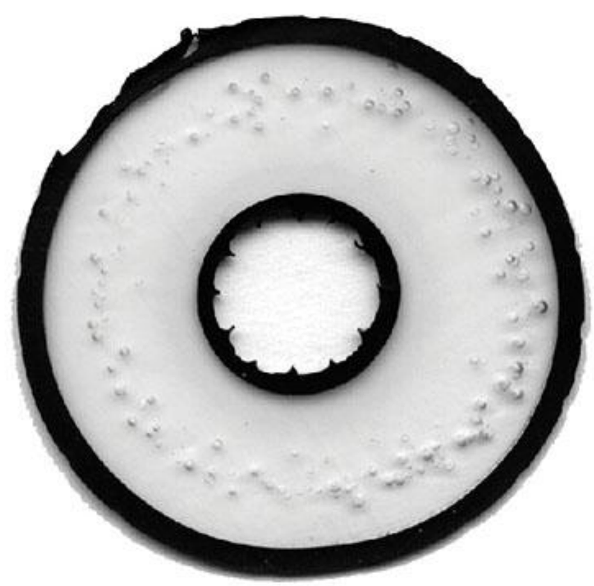

Figure 2. Cable wafer with extensive voids

Large vented water tree at a fault site

Water trees can grow in both polyethylene and EPR insulation. **Figure 3** shows a large vented water tree growing from the insulation shield. This water tree has a fault through it. **Figure 4** shows a cable with a forest of water trees, which can be seen without dissecting the insulation. Water trees require both moisture and an electric field in the insulation to grow. If the cable is an older design made and installed before or about 1980, and has extensive water tree growth, one may conclude that the root cause of failure is simply that the cable has reached its normal endof- life. If newer TR-XLPE has extensive water treeing, a manufacturing problem may be the cause. If the cable is supposed to have strand blocking, water absorbing tape, or a hermetically sealed LC shield, and develops extensive water treeing in a short time, investigate the possible root cause as a manufacturing problem, mechanical damage or shield corrosion.

Cable failing from the outside in

Another type of failure is evidenced by signs of burning or arcing on the surface of the semicon. If the burning or arcing becomes extensive, the cable can fail from the outside in, as seen in **Figure 5**. The cause was determined to be a damaged jacket, which led to corrosive ground water entering the cable and causing severe corrosion of the metallic shield.

Compounding the problem of a damaged metallic shield can be high resistivity in the semicon insulation shield. The volume resistivity of the semicon in older cables often increased with elevated temperatures. This effect was demonstrated in the lab as shown in **Figure 6** Figure 6a shows a break made in the taped metallic shield. In Figure 6b, the conductor was energized and carrying current. As the current was increased the cable temperature rose. At about 50º C, the semicon resistivity had increased to the point where arcing took place across the break in the metallic shield.

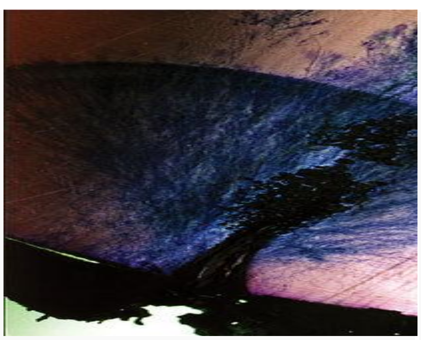

Figure 3. Large vented water tree at a fault site

Figure 4. XLPE cable with a forest of water trees

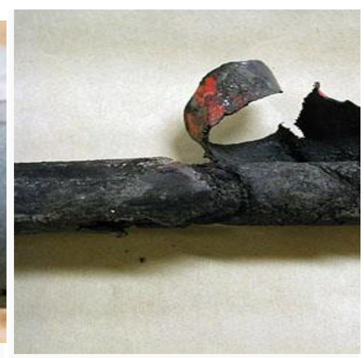

Figure 5. Cable failing from the outside in

Other sources

To investigate a failure in an accessory, in addition to the usual visual examination and gathering of environmental and operating information, other work specific to accessory failure analysis may include:

- Comparing the failed accessory with undamaged accessories in adjacent phases
- Measuring contact resistance in connectors

- Careful dissection of the accessory comparing dimensions with assembly drawings
- Looking for signs of poor workmanship
- Looking for signs of surface tracking
- Looking for electrically floating metal electrodes.

Problems in connectors are a common cause of accessory failure. **Figure 7** shows a drawing of a load-break separable insulated connector (SIC). Within the elbow, bushing insert, and bushing well that make up the SIC, there can be up to eight electrical contacts. Usually problem connectors overheat, which is evidenced by a discolored or burned conductor or insulation. Root cause of the failure is often improper installation including bad connector crimps, cross threading of the elbow probe, or a broken stud in the bushing well. Some older load-break SICs had design flaws in the contacts in the load break mechanism.

Figure 8 shows an XLPE cable end, which was removed from a failed pre-molded splice. The results of arcing can be seen on the insulation surface. When the installer penciled the insulation, burrs were left on the end of the insulation and the surface was very roughly sanded. When the insulation was inserted into the splice body, semicon material was dragged over the surface. The semicon material led to surface tracking and eventual flashover. The cause of the failure was poor workmanship. One might conclude that the root cause is poor training, installation processes or standards.

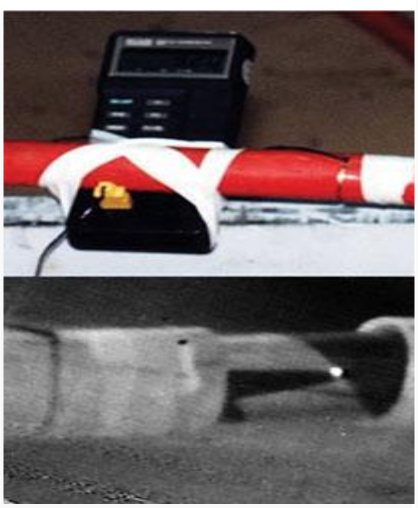

Figure 6. Lab test showing shield arcing due to elevated semicon temperature

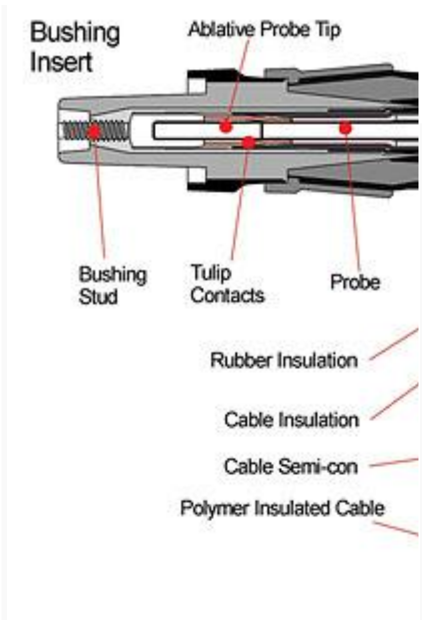

Figure 7. Elbow and Bushing Insert Drawing

Figure 8. Poor Workmanship Leads to Failure in Pre-molded Splice Installation

Summary

Determining the root cause of a cable failure can lead to better maintenance practices, produce more reliable operation, and lower operating costs. Root cause analysis requires a systems approach, which includes understanding the cables, their accessories and operating environment.

References

1. Finding the Root Cause of Power Cable Failures By: Vern Buchholz, P.Eng., Director of Electrical Technologies, Powertech Labs Inc.

Source:

http://www.openelectrical.org/wiki/index.php?title=Power_Cable_Failures