ROOT CAUSES and REMEDIAL MEASURES FOR CABLE FAILURES

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ABSTRACT

Essentially all utilities and large industrial electrical networks extensively use power cables. Many of these cable systems are ageing due to environmental effects and stresses as a consequence of failures of cables are becoming common. As most of cable failure root causes can be traced back to manufacturing, installation and operation phases, ideally cable asset management should begin at an early stage and continue through the cable life cycle. Finding the root cause of cable failures can lead to better operation & maintenance practices and produce more reliable operation in the future. This in turn will lead to lower operating cost with higher reliability.

In this article, types of common and specific cable failures are discussed. Case studies on cable non-conformance and faults are described. An attempt has been made to identify the probable root causes and indicating pre-requisite recommendation(s) to mitigate the associated risks due to cable defect.

Key words: Power Cables, Cable Failure, Root Causes, Remedial Measures

1. INTRODUCTION

Since many decades, cables have been playing an important role in electrical power utilities and large industrial facilities. Cables are considered to be the live elements to transfer electrical power and continue the operation of power systems. At power station, the electricity is generated and then transmitted for utilization of energy for various useful purposes. In general, the transmission, distribution and utilization of electricity is carried through overhead lines or underground cables. In underground power transmission network trouble free cable performance is of extreme importance to all concerned. The aging of existing installations is unavoidable, which may certainly reduce the useful life of power cables. Failures due to ageing are becoming common now-a-days. Any premature failure of cable in a system results in severe problems such as huge economic losses, unsafe operation etc. Failures of cable systems are disruptive, expensive and hazardous and result in loss of vital services. In view of these it is really necessary to find out the root cause of failures and remedial measures to overcome these failures. 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.

Root cause analysis requires a systematic approach. The cables may fail due to any combination of electrical, mechanical or thermal factors.

2. TYPES OF COMMON DEFECTS IN LV CABLE

(A) Failure due to conductor
- (1) High conductor resistance
- (2) Poor tensile strength
- (3) Poor flexibility

(B) Failure due to insulation and sheath
- (1) Low insulation resistance
- (2) Uneven thickness of insulation and sheath
- (3) Poor mechanical properties of insulation and Sheath
- (4) Poor thermal stability

(C) Failure due to whole cable
- (1) Not withstand the applied voltage
- (2) Due to increase in capacitance
- (3) Lower Flame retardant property

(D) Failure due to lower FRLS property
- (1) Less value of oxygen index
- (2) High smoke density rating
- (3) High value of Halogen acid gas content

3. FAILURE DUE TO CONDUCTOR

The conductor is the current carrier of the cable and the most important part of cable. Conductors are usually either of Copper or Aluminium. They can be solid in small sizes or stranded in larger sizes for better flexibility. The size of conductor is determined using current carrying capacity and cable surroundings. Cable does not meet the requirement of relevant standards if the measured conductor resistance is higher than the specified value.

Root Cause of High conductor resistance
The electrical resistance of conductor is one of the important factors for system design and selection of system parameters. When current is flowing through the cable, due to conductor resistance R, the energy loss occurs in the form of I^2R loss. The resistance of conductor depends upon dimensions,

construction, temperature and resistivity constant of the used material. There are several reasons for higher conductor resistance. One reason for higher conductor resistance is the difference in number of strands used to manufacture stranded conductor is different at both ends. So, even if the best material is used, it will lead in higher conductor resistance. Also, poor workmanship, unskilled operators, moisture penetration in the conductor and poor quality of raw materials, leads to higher conductor resistance.

Remedial measure to minimise the conductor resistance

Number of strands should be equal at both ends and size of each strand must be same throughout the length. Copper conductor commonly used for cables must be of electrical grade i.e. 99.9 % purity level. . Volume resistivity of conductor material should be as per design parameters. Maintaining conductor temperature will help to keep the resistance within acceptable limit and reduce the amount of power loss & conductor heating. Use of larger conductor will have a lower resistance due to increased volume of conductive material. As the resistance is determined by the material and material volume resistivity, more volume of material results in lower resistance. In case of power cable conductors, before the copper wires emerging from the drawing process can be stranded, they must undergo annealing. Annealing is necessary to remove some of hardness and stiffness from the copper wires and to return the conductivity of copper wires to an acceptable value. Copper commonly used for cable conductor is 99.9 % pure, the remaining 0.1 % comprising of both metallic and non-metallic impurities. One of the reasons for copper conductor failure is if copper is not proper annealed. Annealing is usually carried out in an inert atmosphere at temperature of about 600 deg C for period of one hour or more. So in view of this it is necessary to evaluate the conductor resistance as per IS 10810 part-5.

Root Cause of Poor tensile strength of conductor.

Tensile strength of conductor is important factor in cable because cable conductor is to be pulled from one end along trenches and is subjected to considerable tensile force during pulling as well as manufacturing process. It is necessary to ensure that the conductor material has adequate tensile strength.

The root cause of poor tensile strength of conductor is impurities in the material and improper annealing process of conductor.

Remedial measure to improve the tensile strength of conductor

By using aluminium conductor in cable applications with usually better than 99.5 % purity with DC resistivity of 2.8 μΩ-cm at 20 deg C. All aluminium conductors used in electrical applications are annealed and tempered. Annealing of commercially pure Aluminium is normally carried out at a temperature of 350 deg C for relatively short period. With Aluminium wires, the annealing process is more refined because care must be exercised to ensure proper tensile strength and elongation. The drawn Aluminium wires must undergo what is termed a continuous annealing process.

4. FAILURE DUE TO INSULATION

Insulation is the second important part of any cable, next to the conductor. Insulation material means a material having required dielectric properties, which is used to separate or isolate the conducting electrical parts.

Root cause of low insulation resistance

Moisture in insulation can cause lower insulation resistance. Moisture in the insulation can also cause significant problems including short circuit and corrosion of the copper conductors.

Excessive heating of the cable will cause degradation of insulation and sheathing material and premature failure. Insulation is subject to many effects which can cause it to fail, i.e. electrical stress, mechanical damage, vibration, excessive cold or heat, dirt, oil, moisture from processes, or humidity. Electrical stresses particularly sustained overvoltage or impulses caused by faults will lead to discharges in voids, which will thereby expand and can develop into electrical treeing. As pinholes or cracks develop moisture and foreign materials penetrate the surfaces of the insulation, providing a low resistance path for leakage current. Any impurities in the material or mechanical imperfections arising during manufacturing of the cable results into loss of quality of the cable. The ageing process is also the reason of eventual failure of insulating materials.

Remedial measure to improve the insulation resistance

Precaution should be taken for temperature control during the application of insulation. Master batch used for colour to insulation should be in proportionate ratio.

Root cause of uneven thickness of insulation and sheath

Adequate thickness of insulation and sheath is provided to power cable to meet the voltage stresses and mechanical stresses imposed on it during its service life. The measurement of such thickness is necessary to verify whether it is as per specified limit or not. These dimensions ensure safe and reliable performance of the cable. Before determining the insulation thickness of a wire, some knowledge of how breakdown mechanisms work in wire insulation systems is beneficial. Breakdown voltage in a wire depends on insulation thickness, insulation material, whether the voltage is AC or DC, and environmental factors such as temperature, pressure, humidity, and how the cable is mechanically attached. The phenomenon of uneven thickness is due to the problems of wire and cable extrusion, namely

(1) Screw or traction instability, resulting in uneven diameter of the cable. Because of the sudden instability of traction, the formation of plastic cables, (such as bamboo-shaped).

(2) Poor mould matching resulting in the semi-finished products outside diameter changing greatly, causing the plastic layer thickness of the cable uneven.

(3) The speed of the retractable line or traction is uneven.

(4) Screw speed instability. The main motor speed is uneven, belt too loose or slippery.

(5) Non uniformity in diameter of the conductor and in thickness of insulation throughout the length of wires, i.e., the conductor is not in the exact centre of insulation material. Such wires cause the increase in possibility of short circuits and are produced due to the use of obsolete and sub-standard machinery

Remedial measure to improve the thickness of insulation

(1) The speed of the screw, traction and take-up line should be always checked.

(2) Mold matching should be appropriate to prevent the phenomenon of reverse glue.

(3) Constantly check the operation of machinery and electrical equipment. Found problems should be immediately repaired/addressed.

(4)Thoroughly check on the raw materials, with proper records of cross checks at each stage, and using pure bright electrolytic copper & PVC Compound.

(5) Use modern and standard machinery to provide exact centricity of conductor in wires. This helps to overcome the problem of uneven thickness of insulation. Thus the distribution of electrical charge from the conductor will be uniform on all sides for insulation.

Root cause of poor mechanical properties of insulation and sheath

The mechanical properties of insulation and sheath is determined by tensile strength and elongation at breaking point. During installation, electrical cables are unavoidably subjected to mechanical stresses, particularly bending. The insulation and sheath of the cable should have adequate mechanical strength to withstand these stresses and strains. If the additives in the insulation material are not proper then there may be chances of tensile strength and elongation at break failures.

Mechanical failures can be due to breaks and defects of sheath material, mechanical punctures by people or machines, or cracks due to sharp bending or vibration. Whenever mechanical damage occurs in the cable sheath, the entrance of moisture will produce slow deterioration of insulation material, resulting in eventual failure of the cable.

Remedial measure to improve the mechanical properties of insulation and sheath

It is important therefore to take every precaution that either direct or indirect mechanical damage can be eliminated or minimized by correct selection, installation, and maintenance of cable systems.

Root cause of poor thermal stability of PVC insulation and sheath

The thermal stability is an accelerated method to determine the rate of degradation of PVC compound with time under the influence of temperature. Thermal stability is the indication time in minutes, indicated by the red coloration of pH paper produced by the evolution of hydrochloric acid when PVC compound is heated to optimum temperature.

In order to avoid material decomposition; for PVC, the main decomposition problem occurs by the de-hydro-chlorination, consisting in the production of hydrogen chloride and starting at temperatures in the range 520-590 K for commercial PVC. However, even at lower temperatures problems like thermal degradation can occur; in particular burns and surface whitening phenomena begin to appear at temperatures around 110 453 K, leading to cable defects.

Remedial measure to improve the thermal stability of PVC insulation and sheath

By adding additives stabilizers in PVC polymer to minimise the effect of heat and thermal stability can be increased.

5. FAILURE DUE TO WHOLE LV CABLE

Root cause of notwithstanding the High voltage

If the cable insulation is weak, thickness of insulation is less and the cable used is underrated then there may be chances of failure in high voltage test. Electrical breakdown takes place owing to admission of moisture, excessive bending, elongation, interfacing etc.

6. FAIULRE DUE TO LOWER FRLS PROPERTY

(1) Less value of oxygen index
(2) High smoke density rating
(3) High value of Halogen acid gas content

7. CASE STUDIES

Based on our wide experience on testing of cables as per national and international standards, the following case-studies on failure of LV and HV cables are presented.

Table 1: Case study details

Case Study	Type of cable	Type of failure observed
1	1 Core x 25 sq.mm XLPE LT cable	Conductor Resistance
2	2 Core x 2.5 sq.mm LT PVC cable	Insulation Resistance
3	3 Core x 50 sq.mm + 1C x 16 sq.mm +35 sq.mm XLPE insulated unsheathed AB cable	Hot set test
4	4 Core x 25 sq.mm LT PVC cable	Insulation resistance

Case Study # 1: XLPE cable failure

- Cable details : 1 Core x 25 sq.mm XLPE LT cable tested as per IS 7098 Part-1

Type of failure : Conductor resistance failure

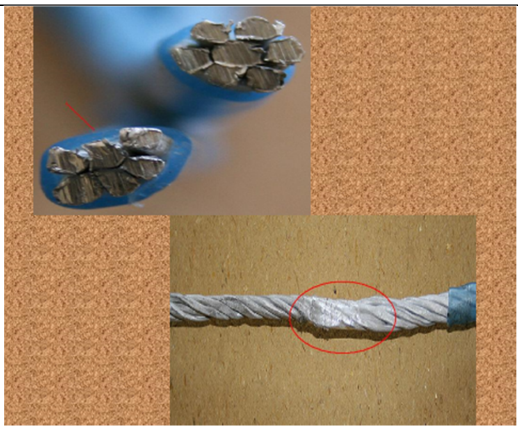

Figure 1. Different strand of conductor at both end

In above case study, the conductor resistance test is carried out as per IS 10810: Part-5. The observed conductor resistance at 20°C is 1.38 Ohm/km against requirement of Max. 1.20 Ohm/km. With detailed analysis it was found 7 strands of conductor at one end and 6 strands of conductor found at the other end. Also there is a joint found in between.

This happens if we do not take care during manufacturing process of cable conductor. Uneven strands are attributed in manufacturing process and lack of Quality control measures, material conductivity.

Such types of errors may be overcome by using accurate diameter of conductor as per design parameters. Conductor strands must be verified automatically and also the conductor resistance can be monitored at equal length of conductor during manufacturing process.

Case Study # 2: PVC cable failure

- Cable details : 2 Core x 2.5 sq.mm LT PVC cable as per IS 694

Type of failure

Insulation Resistance failure

Figure 2. Conductor open in LV PVC cable

In this test, the test specimen is required to prepare as per IS 10810 –Part 43, In above case study while preparation of test specimen insulated core is to be taken by removing outer sheath of cable. It was found that at the different length intervals conductor was not uniformly insulated and also at some of the places conductor was found not insulated.

Such types of errors can be removed during the manufacturing process by controlling temperature of extrusion process. Stage-wise physical inspection and measurement of insulation thickness is also necessary at equal time intervals during entire manufacturing process.

Case Study # 3: Aerial bunched cable

- Cable details : AB cable – 3 Core x 50 sq.mm + 1C x 16 sq.mm +35 sq.mm XLPE insulated unsheathed AB cable as per IS 14255

In above case study during Hot set test as per IS 10810 –Part 30, the test specimens were prepared and suspended in the oven and weights were attached to the bottom grip as per the test conditions. Suddenly the sample broke & it did not withstand the mechanical stress of 20 N/cm^2 at 200 °C for 15 minutes.

Such types of failures might be possible if the curing process of insulation is not adequate. To overcome such type of issues, proper curing time, curing method and curing temperature are to be maintained as per requirements.

Case Study # 4: PVC cable

- Cable details : PVC cable – 4 Core 25 sq. mm LT PVC cable as per IS 1554

Type of failure : Insulation resistance failure

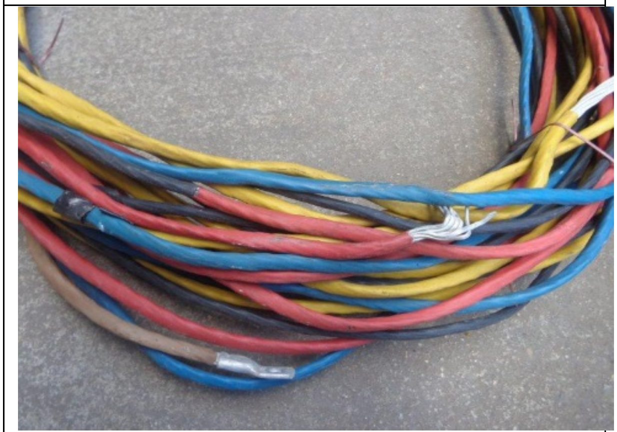

Figure 3. LT PVC cable

In this case study Insulation resistance test was carried out as per IS 10810 Part-43. During testing it was found that the insulation did not withstand 500 V DC for one minute. By visually inspection of insulation, it was observed that there was no crack or pin holes on the outer surface of the PVC insulation. The probable cause of failure may be due poor quality of material used for PVC insulation or moisture penetration. Also, the Ingredients used for colour of insulation may in excess quantity rather than the required quantity.

These problems can be overcome by selecting approved PVC material for insulation. The ratio of ingredients used for colour of the insulation shall be as per defined value.

Case Study # 5: XLPE cable

- Cable details : 1 Core x 400 sq.mm, 33 kV Al conductor XLPE insulated PVC outer sheathed armoured HT XLPE cable as per IS 7098 Part-2: 2011

Type of failure : Sheath failure

Figure 4. HV XLPE cable

This case study impact on the poor workmanship at user end. During the laying of single core cable

many time outer sheath get damaged and because of that multi earthing of armour will be developed. Normally for single core cable earthing should be done at one end of cable while other end of cable screen/armour is connected to earth through SLV (Sheath Limiter voltmeter).

The above photograph shows such failure occurred at field due to damage of outer sheath of single core cable.

Care to be taken while laying of the single core cable and after laying ensure that there is no multi earthing of screen/armour through IR meter at 500 V dc.

Acknowledgements:

Authors wish to thank the Management of Electrical Research and Development Association (ERDA), Vadodara – India for giving permission to present this paper. Authors would also like to thank all the engineering offices of “Cable Laboratory” for providing all required details for writing the paper.

8. CONCLUSION

To prevent cable defects, stringent stage wise inspection to be implemented at manufacturer end to improve the final product quality. After commissioning and before charging the HT cable Insulation resistance test to be carried out to check the multi earthing of screen for single core cable.

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