A new rejuvenating technique for cable localized insulation failures of railway locomotives

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Abstract. A new rejuvenating technique, injection plastic technique with standard scales and over coatings, is developed for restoring the localized cable insulation failures of railway locomotives. The materials of cable jacket and insulation layers are pelt with standard scales around the localized fault location. The failed materials are treated visibly to eliminate hidden perils. Matched moulds with over coating spaces are creatively designed and manufactured for rejuvenating cable insulation and jacket layers materials with injection moulding machine. The policies of standard scales and over coatings can well ensure a reliable rejuvenation, good bound seals and well economic benefits.

1. Introduction

1.1. Background

The cables on railway locomotives are applied for transferring the electric power which have around 25 kV with 50 Hz introduced by pantograph to rectification which have 1000~1600 V with 50 Hz for work equipments such as traction motors etc. Once an insulation failure occurs and the electric power can’t be normally transferred to the equipments, railway transportation has to be interrupted. If a failure occurs locally but most of part of the insulation material is still good, replacing will bring a not good economic benefit. Therefore, rejuvenation technique is expected but must be reliable.

1.2. Cable failure patterns

Mason [1] researched earlier in 1955 the cable insulation material breakdown in divergent fields. Kitchin-Pratt [2] noticed treeing phenomena in 1958. From existent research achievements, three kinds of patterns can be summarized in Figure 1 under reflecting cable failure mechanisms. They are electric treeing, water treeing, and mechanical damaging.

1.2.1. Electrical treeing. Insulations of cables are generally constructed with material of a polyethylene (PE) or a cross-linked polyethylene (XLPE). By existent technical conditions, there are defects including inclusions, micro-voids and inhomogeneous microstructures for the materials. When cable(s) are working, the defects are interacted with the service conductor(s) which may develop local higher electrical electromagnetic field to produce local higher electrical voltage and disrupt the defects even to form electro-discharging channels. Treeing and branching structures grow gradually up. Some important characters have been revealed such as the frequency related fractal profiles [3, 4], critical
parameters for tree formations [5] and threshold voltages for electrical tree inception [6].

1.2.2. Water/liquid treeing. In liquid environment such as water around cable conductor, the tree should initiate from and grow along water affected specific sites. Inception involves the local accumulation of water elements at imperfections in the insulation (bow-tie treeing) or at the insulation-conductor interface sites (vented treeing). Particularly if the electric fields are inhomogeneous because of imperfections, the dipolar water molecules will migrate towards into the imperfections. Further local water accumulation may lead to a liquid phase, particularly if the imperfections as impurities are present in micro-voids. Therefore, the trees emerged from the liquid/water environments should be named as liquid/water trees [7].

Summing up existent research achievements, it is known that mechanisms, characteristics and behaviour laws of liquid/water trees have been well studied. Inceptions and growths of the water trees carried out due to partly the concurrence characters of insulation materials and partly the competition of specific aging conditions. Oxidation, chain scission and diffusion are important elements affecting the water tree growth. Propagation processes are occurring at service stresses particularly at electro-osmosis and oxidative environments on the basis of chemical composition and dielectric properties. The degradation is therefore a result from both electrochemical and electro-physical natures [8].

1.2.3. Mechanical damaging. Cable insulations may be failed due to various uncertain mechanical forces such as excessive bending or/and twisting in a manhole or duct in the course of installation or transport due to various kinds of foreign objects may fall on the cables in a manhole in service [9]. In some service environments such as submarine, mechanical damaging occurred easily [10].

![Figure 1. Three kinds of cable failure patterns.](image)

1.3. Existent rejuvenating techniques

From the above introductions, it has indicated that aging and degradation are intrinsic phenomena of insulation materials because of the material defects interactive with service electro-magnetic field and uncertain work conditions [11]. Facing this case, rejuvenating techniques were emphasized on ensuring reliable work of cables and the financial economical benefit.

1.3.1. Injection solutions/liquids. A wide applied technique, injection solution, is an existent rejuvenating technique wide applied. By this technique, cables having stranded conductors were flushed with a gas such as dry nitrogen or filled with a special liquid such as a silicone solution. The flushed dry nitrogen remove the moisture and then the liquid permeates subsequently into the insulation material to improving or restoring the material functions. So that cable insulation lives can be extended [12].

1.3.2. Filling materials. As for the mechanical damaged failures, a cold sticky rubber band has been suggested to pad on the damaged sites of cable for temporary treatments of cable insulation failures [13]. And heating device was also proposed for conducting flowed rubber filling up the damaged space(s) to restore cable insulation function [14].
1.4. Present work
Considering the obvious shortages revealed below, a new rejuvenating technique, injection plastic with standard scales and over coatings, is proposed by author’s team. The present paper is to introduce this technique.

2. Shortages of existent rejuvenating techniques
Obvious shortages should be noted below for the existent rejuvenating techniques:

2.1. Invisibility for human eyes
The injection solution/liquid technique can be carried out without visible conditions for human eyes. True situations of insulation material around failure sites can be only known by help of microscopy or other aids of equipments. In addition, the micro-vision can be realized under laboratory testing. So, repair effects and quality are difficult to be evaluated.

2.2. Invalidation on economic benefit
Mechanical damaged profiles of cables are mostly varied with different production details. So, the devices for the spaces of filling of damaged insulation materials should vary with different damaged profiles, which rise repairing cost even to result in a result without economic benefits.

In addition, for the bounds between filled materials and original materials the existent technique has not proposed a reliable measure.

3. New rejuvenating technique
For the cables applied on railway locomotives, the insulation materials are naturally subject to physical aging and possible mechanical damaging during installation and transportation. To avoid the above shortages of the existent rejuvenating techniques of cables, new technique(s), injection plastic with standard scales and over coatings, is proposed for achieving well economical benefit and repair reliability of localized cable insulation failures. The present new should be introduced with the indications on advantages.

3.1. Standard moulds for achieving good economic benefits
In present new technique, standard moulds are creatively suggested for overcoming the above mentioned shortages of the above rejuvenating technique for mechanical damaging, which did not consider the standard moulds. The author’s team proposes the present moulds reminded from following elements:

The materials for cable insulation function are generally polyethylene (XLPE), ethylene propylene rubbers (EPR), and polypropylene (PP) which have thermoplastic character. They are applied in the form of coating around conductors to manufacture cables through an extruding press process. These materials hold physic aging to degrading characters to have a concept of limited life. But comparing to conductors, they are generally much cheaper with shorter lives. Therefore, when insulation lives close to an acceptable level of material limited lives, replacing may be an optimal selection from consideration of production economic benefits. For this case, the rejuvenating should be reliable with good economic benefits.

But for case of localized cable insulation failures, a non-replacing policy should be benefits if repairing equality can be ensured. Combining with following over coating policy which can well ensure repairing equality, the present new technique is proposed to use the technical policy of standard moulds. By the policy, one set of moulds can be applied for the rejuvenation of various localized cable insulation failure with varied damaged profiles.

3.2. Over coatings for ensuring rejuvenating quality
To ensure rejuvenating quality, over coating policy is further proposed with systematic creations. Details should be indicated below.
3.2.1. Development of appropriate insulation and jacket materials. Materials for rejuvenating the insulation and jacket layers were developed through processes, as shown as in Figures 2 & 3, of chemical composition identifying, material manufacturing-performance testing ruled by code TB/T 1484.1 for the cables of railway locomotives.

Figure 2. Development of materials for rejuvenating cable insulation and jacket layers.

Figure 3. Identifying and approving on materials of cable insulation-jacket layers.

3.2.2. Visible and over coating. As shown as in Figure 4, the original materials of jacket and insulation layers around cable localize fault location are pelt with standard scales. By this treatment, the failed materials including hidden perils can be cleaned under visible situations.

For rejuvenation of insulation layer, an special mould, who has the over coating space with diameter scale from \( \phi B \) to \( \phi B + 2\delta_2 \) plus the over coating length \( L_\delta_2 \), is creatively designed and manufactured to ensure reliable rejuvenation with well bound seal.

For rejuvenation of jacket layer, as shown as in Figure 5, a jacket layer mould, which has an over coating diameter space from \( \phi A \) to \( \phi A + 2\delta_1 \) plus the over coating length \( L_\delta_1 \), is creatively designed and manufactured to ensure reliable rejuvenation with good bound seal.

In addition, by the present technique only one set of special moulds for insulation and jacket layers are needed and, therefore, good economic benefit can be achieved.

4. Conclusions
Following conclusions have been achieved by the present research
Figure 4. Standard scale and over coating technique for rejuvenating cable insulation layer.

Figure 5. Standard scale and over coating technique for rejuvenating cable jacket layer.
• Aging and degrading are natural phenomena of cable insulation and jacket materials. Invisibility to affect rejuvenating effects is a main shortage of existent injection solution rejuvenating technique.
• A new rejuvenating technique, injection plastic with standard scales and over coatings, is developed for restoring cable localized insulation failures of railway locomotives. Materials of cable jacket and insulation layers are pelt with standard scales around the fault location. Failed materials are treated visibly to eliminate hidden perils. Matched moulds with over coating spaces are creatively designed and manufactured respectively for rejuvenating cable insulation and jacket layers. A reliable rejuvenation is gotten by the policy of over coating with good bound seals and a good economic benefit is achieved with the policy of standard scales of moulds.

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References
[1] Mason JH (1955) Breakdown of solid dielectrics in divergent fields. Proc IEE, Part C, 102: 254-263.
[2] Kitchin DW, Pratt OS (1958) Treeing in polyethylene as a prelude to breakdown. AIEE Trans PAS, 77: 180-186.
[3] Zheng XQ, Chen G (2008) Propagation mechanism of electrical tree in XLPE cable insulation by investigating a double electrical tree structure. IEEE Transactions on Dielectrics and Electrical Insulation, 15(3): 800-807.
[4] Chen G, Tham CH (2009) Electrical treeing characteristics in XLPE power cable insulation in frequency range between 20 and 500 Hz. IEEE Transactions on Dielectrics and Electrical Insulation, 16(1): 179-188.
[5] Jiang G, Kuang J, Boggs S (1998) Critical parameters for electrical tree formation in XLPE. IEEE Transactions on Power Delivery, 13(2): 292-296.
[6] Bamji SS, Bulinski AT, Chen Y, Densley RJ (1992) Threshold voltage for electrical tree inception in underground HV transmission cables. IEEE Transactions on Electrical Insulation, 27(2): 402-404.
[7] Bahder G, Katz C, Lawson J, Vahlstrom W (1974) Electrical and electro-chemical treeing effect in polyethylene and crosslinked polyethylene cables. IEEE Transactions on Power Apparatus and Systems, 93(3): 977-989.
[8] Ross R (1998) Inception and propagation mechanism of water treeing. IEEE Transactions on Dielectrics and Electrical Insulation, 5(5): 660-680.
[9] Takagi T, Takahashi S, Tabata T, Kikuchi K (1967) Characteristics of Mechanically Damaged Single-Core Oil-Filled Cable. IEEE Transactions on Power Apparatus and Systems, 86(5): 582-591.
[10] Arnaud U, Buzzi G, Valenza D (1990) Advantages and disadvantages of embedment to prevent external mechanical damages to submarine cables. IEEE Transactions on Power Delivery, 5(1): 54-57.
[11] Thomas AJ, Saha TK. (2008) A new dielectric response model for water tree degraded XLPE insulation-Part B: dielectric response interpretation. IEEE Transactions on Dielectrics and Electrical Insulation, 15(4): 1144-1152.
[12] Zhou K, Tao XT, Wang XJ, Zhao W, Tao WB (2015) Insight into the new role of titanium isopropoxide catalyst on rejuvenation for water tree aged cables. IEEE Transactions on Dielectrics and Electrical Insulation, 22(1): 611-618.
[13] Wang JH, Ma LM (1996) A cold sticky rubber band for rejuvenation mining cable. China: CN2272624Y, 1996-01-26 (in Chinese).
[14] Teng H (2016) A equipment for rejuvenation damaged insulation of cable with supporting [P]. China: CN201620322979, 2016-04-18 (in Chinese).