PRESENTING A NEW METHOD TO ESTIMATE THE REMAINING LIFE OF AERIAL BUNDLED CABLE NETWORK

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ABSTRACT

Today, the aerial bundled cables (ABC) are gradually finding their place in low voltage electrical network around the world and especially in the Middle East and respectfully Iran due to the benefits that are superior to the wired network. In recent years, around 70% of the low voltage power network in Iran has replaced by ABCs.

This paper introduces a new method of ABC's life expectancy that can be useful for electrical network operators. They can be informed about the useful life of ABCs before serious damage happen and take remedial activities such as repair or replacement of the network. Firstly, the erosion processes in ABCs are introduced, and then using the factors of influence on the aging, and the math formula a chart for determine the remaining life of the ABC will be presented.

INTRODUCTION

During recent years, the process of changing bare copper wires to the aerial bundled cables (ABC) is accelerated so rapidly. Regarding the concern of ABC's lifetime, there is an important question among engineers and senior managers of the electrical distribution company that whether ABC is a good alternative for bare wire or not? Answering this question is highly related to determining the useful life of ABC as accurately as it could be.
Obviously, due to the shorter lifetime of ABC insulator, this cable has a shorter lifetime than copper or aluminum wires. In order to find the true value of ABC's life, important factors and parameters in erosion should be recognized. Due to the growing use of ABC networks across the countries, poor information and maintenance instructions and procedures troubleshooting are high-lighted.
Based on the experience gained in the Shiraz Electricity Distribution Company (SHEDC) the most important factors in shortening the lifespan of the ABC network are not following the standard quality from the manufacturer and the use of nonstandard hardware and clamps. In return, correct maintenance and operation of the ABC network and unified set of instructions will be helpful [1]. To estimate the ABC life, it is required to specify the mechanisms that cause errors, failures and aging.
It is possible that the cable insulator shield is corrupted during the construction, transportation or operation procedure, and so the insulator failure starting [2]. Partial discharge is another influencing factor that may results in breakdown. The main reasons of PD are built of voids and sharp electrodes [3, 4]. Water tree phenomenon is another aging mechanism in extruded cables [5].Besides, wrong cable operation and designing of cable size would be influential in life of cables.
In the following sections the major influencing factors on aging are introduced. After that, by using the mathematical methods and experiments obtained in SHEDC a curve is proposed for life expectancy of ABC.

1. INFLUENCING FACTORS ON AERIAL BUNDLED CABLE LIFETIME REDUCTION

Research shows that several factors are responsible of deterioration and reduction of the useful life of ABCs. Factors such as mechanical damage, moisture penetration to cable insulation which is caused by hardware installation, use of non-standard clamps and cultural factors of the area as well as weather conditions are the most important ones. Meantime, it is proven that the cable insulation play major role in cable useful life. As a result, the cable insulation is a good indicator for calculating the remaining life in the ABCs. So that it can be said that the determination of the time duration break down of the insulator in cable is equivalent to the remaining lifetime of ABCs.

2- AERIAL BUNDLED CABLE WITH POLY ETHYLENE CROSS LINKED INSULATOR

Compared to the other cables, ABCs have better thermal specification, withstanding temperature, dielectric loss and installation cost. Cross linked cables are able to work up to 90 centigrade. Temperature increase has a great role in life time of insulator. The temperature increase affected by parameters such as the maximum working temperature allowed for cable, the environment temperature and cable insulation structure. Cable rated current must be designed to use throughout the year for the worst case and can withstand the highest temperature.
With increasing temperature, the polymer material has major change in the chemical qualities which results in physical characteristics shifts. For this reason, protection the polymer used in cable especially at high temperatures to obtain the optimum time in operation is important.
Due to the loss of the cable insulation at high temperatures, releasing of heat to the environment is an

essential item. Moreover, the cable insulation must protect against the explosion of sunlight (UV).
Research shows that black carbon is a good stabilizer for poly elfin. The presence of oxygen in the air causes rapid aging of the family of chemical compounds, polymers (including poly elfin) and factors such as temperature and light intensity this procedure [6].
The cross linking process is created by various conditions such as high temperature heating cable in the steam room. This process changes the chemical structure of PE that increases the threshold withstanding to heat. In relation (1) the chemical structure of XLPE insulator illustrated.

$$\boldsymbol{XLPE - Homopolymer + (EEC\ or\ EBC) \rightarrow XLPE - Copolymer}$$
$$\boldsymbol{XLPE - Homopolymer = -CH_2 - CH_2 -}$$
$$\boldsymbol{EEC = -CH_2 - CH_2 - CH - CH_2}$$
$$\boldsymbol{C = O}$$
$$\boldsymbol{O}$$
$$\boldsymbol{C_2H_5}$$
$$\boldsymbol{EEC = -CH_2 - CH_2 - CH - CH_2}$$
$$\boldsymbol{C = O}$$
$$\boldsymbol{O}$$
$$\boldsymbol{C_4H_5}$$

Relation 1: Chemical structure of ABC insulator

3- FACTORS AFFECTING ABC LIFE TIME

Research has shown that several factors affect the deterioration of aerial bundled cables network and reduce the useful life of them. Factors such as mechanical damage, scarring or penetration of moisture into the cable insulation through the fittings, use of non-standard clamps, cultural factors and weather conditions concerns. In this section, we mention a few effective indexes.

3-1 Cable Insulators

There are several phenomena in nature that causes the loss of the cable insulation and the gradual deterioration of aerial bundled cables. Several factors such as clash of adjacent trees, dragging on the ground and on the sharp rocks, intentional injuring to catch unauthorized branching and non-implementation of standard clamps principally are make serious damage in cables. This eases the water penetration into the cable and creating the phenomenon of the water tree over time.
In water tree phenomenon the water penetrates in the cable shell, and then converts to steam and causes the expansion [5]. This procedure causes small cracks in insulation layer and slowly grows so that the insulation properties decrease rapidly.
Another influential parameter that creates the water tree is voltage. The initial water tree and its growth is a function of the electric voltage at that point. This voltage should be between conductor and insulation cable layer.
The average voltage must be between 2 to 8 KV/mm and its frequency is 50 or 60 Hz. In figure (1) the water tree phenomenon is shown.

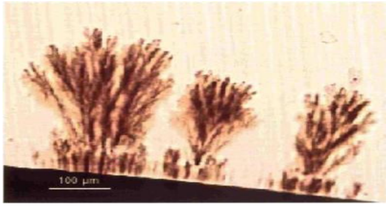

Figure 1: The water tree phenomenon in PE cables

Experimental results show that the cable insulating material has corrupted after 20 to 30 years of operation.
Therefore, under the pressures, thermal and electrical stresses the XLPE insulator will be suffered greatly [8-10]. If there is no supervision on old cable insulation they are intended to absorb moisture and impurities much more than the new ones. So cable insulator is a good indicator for the remaining life of the cable.
Another phenomenon which causes gradual loss of insulation is partial discharge, which is a critical process in cable lifetime. Usually partial discharge occurs in cable joints and terminal or the location of wounding the cables. It can be expanded with time and eventually lead to the defeat of the electrical insulation and collapse. Operators can reduce the cost of maintenance by determining the weak points and repairing or replacing it in wright time. So knowing the lifetime is essential. In general, determination of the duration left to the electrical breakup of cable insulation is called life estimation. Regular Service and maintenance would be very helpful in reliability and lifetime of cables.

3-2 Clamps

One of the most influential factors in aging ABC is the use of nonstandard electrical connections. This may cause premature aging of the network. ABC insulator layer can be damaged by malfunction or mechanical pressure connectors and the rain water can easily penetrates through cable clamps.
Therefore, the correct guidelines must comply with the implementation of the standard clamps and protect them against water penetration (such as placement of screw clamps to the top or use the rubber linings and grace in them). Notice that there is no permission to take off installing clamps from the network.
The most common reasons for operation group rechecking are not tighten enough the closing screw clamps and not going down steel blade in the cable conductor.

3-3 Temperature

Temperature plays a very prominent role in aging. In order to create the required temperature the electric current is used. Heat cycle can be 8-16 hours daily within a few days of the week. Average ambient temperature for each country and each region varies according to the region and weather conditions as well as the cable installation conditions.

Maximum working temperature of cable in accordance with IEC287 standard for XLPE insulated cable is 90 degrees. Basically the length incensement due to short circuit currents causes expansion in cable conductor and creates problems such as longitudinal advance in multi-wires cables or displacement.

This is happen because of the effects of thermodynamic phenomena. This phenomenon creates electromagnetic force from short circuit currents in the cable that results in cable departure if the wires are not fasten tightly together, thus increasing the length of the cable with the temperature is inevitable.

This increase will be more in aluminum than copper. The ABC cable characteristics necessitate length incensement during hot season even if short circuit not happens. Although cold weather of next year will partly compensate this length growth but over time the length of cable will get bigger. So cable length can be used as a marker for age detecting of cable.

4- MAKING ARTIFICIAL AGING IN LABORATORIES

In order To create the sample ABCs with different lifetime in a laboratory an artificial aging is produced. This action can be done under the mechanical, thermal and electrical stresses which are caused by machines. In the lab to create the required temperatures a proper electrical current would pass through the cable in consecutive cyclic duration of 8 to 10 hours within a few days of the week. Basically, the large rise in the cable temperature resulting from short circuit currents are causing expansion of cable conductor. This expansion causes problems such as longitudinal advance or cable displacement. The increasing longitudinal property of cables can be used as an indicator for detection of the cable age.

The aging action of one piece cable should be done according standard IEC811-1-2. To create lifetime of 5, 10 and 15 years the cable placed in an oven for a week and for 20 years of aging, the duration should be 2 weeks. The oven temperature should be changed so that it matches to natural conditions. In this test, three different temperatures of 60, 80 and 100 °c is of interest, so that 50% of cable life is in temperature of 80 degrees, 25% at the temperature of 60 °c and 25% of it spent in the fitted temperature to 100 degrees. To create erosion in wet environment, the cable can be put on the tank filled with water for a period of 4, 6 and 12 months. In Figure (2) this issue is illustrated.

Figure 2: The water tank used in the laboratory

Voltage is the other affecting parameter in deterioration of the cable. At temperatures higher than 90 degrees, the crystals of insulation are melting and then oxidizing. This leads to the weakening insulation property of XLPE cable. To apply the electrical breakdown voltage (EBV) the needle test is used. This process is controlled by placing a needle into the cable insulation. The depth of the needle is variable and the duration of applied voltage determines the lifetime of cable. In figure (3) this subject is shown [12].

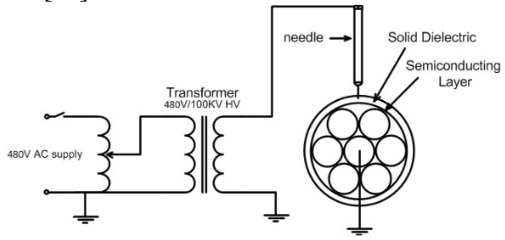

Figure 3: Electrical circuit diagram for breakdown voltage test

5- PRESENTING AGING FORMULA

In this section by using the math functions and the introduced factors a formula for estimating the cable lifetime is presented. The age of the cable operation is modeled by a multi variable function with linear regression. In this function T is the age of cable in years and L is the increasing length and E is the electrical breakdown voltage (EBV). In formula (1), this function is shown.

$$T_{remaining} = a_1 + a_2 L + a_3 E \qquad (1)$$

The a_1, a_2 and a_3 fixed constants and calculated by Eviews software which is one of the best among similar ones. This software calculates the constants by sum of squared residuals method. Putting them in formula (1) the relation (2) is reached. This relation hands out the estimation of cable lifetime.

$$T_{remaining} = 67.19 - .00435L + 2.095E \qquad (2)$$

According to results of needle tests, table (1) is calculated. In table (2) the lifetimes for different cables are calculated by relation (2). The actual data plots of cables length value and electrical breakdown voltage are shown in figure (3) and (4). Finally a comparison among EBV and cables length is done in figure (5).

Table 1: The results of cable length increment and EBV

Cable age (year)	0	5	10	15	20
Cable length increment (mm)	1000	11000	1155	1270	1297
EBV(kV)	13.6	11.6	9.8	8.8	8.7

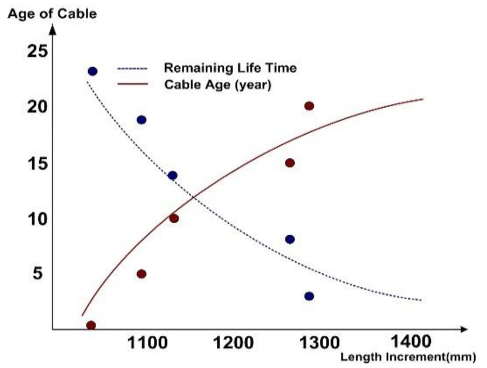

Figure 3: Increasing the length of the cable according to the age of the cable.

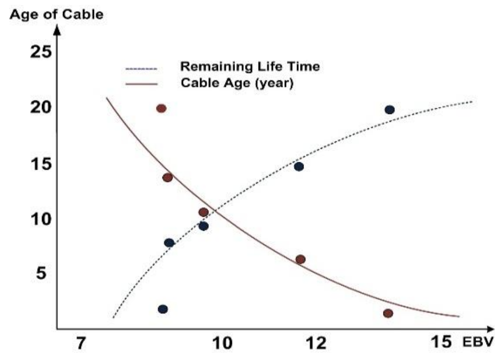

Figure 4: Electrical breakdown voltage vs time.

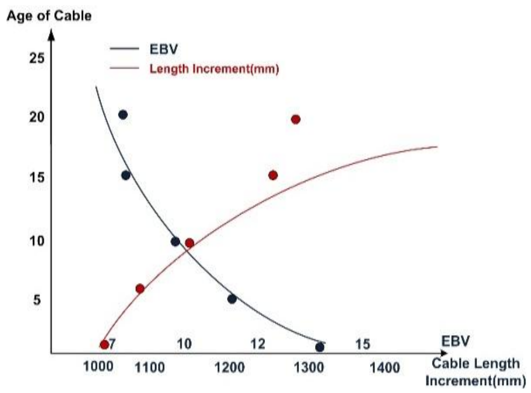

Figure 5: Comparing diagram of EBV and cables length according to the age of the cable.

Table 2: The remaining life of cable

Cable age (year)	EBV(kV)	Cable length increment (mm)	Remaining lifetime (year)
14	9.2	1250	4.97
6	7.8	1090	12.3
8	10.3	1150	13.4

6-CONCLUSION

In this paper the calculation of remaining life of aerial bundled cables are addressed based on the research and experiences of other countries and leading distribution companies.

Analysis the graphs of aging affecting factors in ABC network can produce suitable information for estimating the remaining lifetime. As a consequence, it is possible to answer the question that how long the ABC network will be work properly?

It should be noted that other effective factors in deterioration of cable networks are the rate of unauthorized branches, intentional wounding and climate changing that has a great effect on grid collapse.

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