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Evaluation of the insulation life of dense busbar trunking system based on SVM optimized neural network

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Abstract. For the Busbar with good design and installation ,the most important factors affecting its working life is the insulation aging. Therefore, a reasonable life prediction on its insulating material can ensure it operates safely to some extent. As for the same compact Busbar with insulating materials which are polyester film , life prediction should be made respectively on the used and unused one. Conduct the accelerated thermal aging test first, and then predict its insulation life on the basis of its working temperature distribution last year, according to the Arrhenius equation and the theory of the loss of thermal life; Similarly, predict the residual life of a used one. The results shows that its live is basically the same and reveals that this method can predict the insulation life effectively, and can provide a theoretical basis for the timely replace of a Busbar.

Key words. Busbar, insulating materials, life prediction, accelerated thermal aging, Arrhenius equation.

1. Introduction

Insulation system is an important part in the safe operation of electrical equipment, for the economy and safety considerations, the insulation system must be life prediction. With the development of the national economy, a large increase in electricity consumption in all walks of life,with the high-rise buildings and large workshops and plant a large number of traditional cable in the current high current has been unable to meet the requirements of multi-channel cable parallel use. As a result, the busway has begun to be widely used in real life. Busbar slot is the part of the power system, influenced by the heat, electricity, machinery and other factors, and especially the busbar joints at the temperature are easy to rise. the per-

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formance of insulating materials will be irreversible after the heat down, the busway will eventually fail. Therefore, in order to ensure the safe and reliable operation of the busbar, it is very important to accurately predict the insulation life. At present, scholars have reserched on the power transformer [1, 2], cable life prediction and evaluation of the study.the busway in this area is less research.

However, for well-designed and high-quality busbars, the limiting factor in working life is the gradual aging of its insulating material. Many scholars at home and abroad use the Arrhenius equation to predict the aging of insulating materials. T.W.Dakin [3] explains the exact relationship between thermal aging and thermochemical reactions of certain chemicals. He describes the relationship between the chemical reaction rate and the temperature. Peter H. G ALLEN and Arnold Tustin [4] used the Arrhenius equation to assess the aging of the insulating material and studied it under variable temperature conditions. Some scholars have used Arrhenius to predict cable life, and S.E Kiersztyn [5] of the United States uses Arrhenius to estimate the insulation life of locomotive cables that are subject to heat loads. Ramteke P K [6] has done an in-depth study of cross-linked polyethylene materials in accelerated thermal aging tests to help understand the temperature range to which the Arrhenius equation applies to a particular material. Wang Zhiqiang used [7] Arrhenius method to the predict the life of marine butyl cable, through the thermal aging test and the actual operating conditions to predict its service life. Liu Yaonan who is the one of the founders of China's insulation science and the Beijing Institute of Electrical Appliances had lucubrated the accelerated thermal aging test of polyester film [8, 9] which has been shown to be thermal ageing in accordance with the Arrhenius equation.

At present, there is little research on the prediction of the insulation life of the busway. For the compact busbar.which's insulation material is the polyester film (PET) Firstly, do the thermal aging test of the insulation material of the unused busway and it should combines with the Arrhenius equation for its life prediction; Similarly, predict residual life of used dense busbar which is used for ten years. However, the current prediction of insulation life is usually based on a constant temperature, the temperature which is the maximum value, or the fitting of the temperature value. The former often make the predicted life be greater than the actual value, if the end of life to determine the end of life will cause unnecessary economic waste; due to changes in the temperature of electrical equipment larger ,the latter makes the prediction life error. Based on this, the Arrhenius equation conbined with the thermal life loss theory of Peter HG ALLEN and Arnold Tustin sovle the problem. Based on the measured temperature, a thermal life prediction method based on the actual temperature is found to solve the problem of large in sulation life prediction error large and Predictions Life is less than the actual problem.

2. Prediction of thermal aging life under variable temperature

The polyester film of the compact busbar is a polymer material, and the degradation of the polymer materials is an oxidation reaction. The rate of this chemical reaction is closely related to the temperature. The test shows that the deterioration of the polyester film follows Arrhenius model, the single Arrhenius model can only predict the life model of the insulating material at constant temperature, so for the temperature-unstable busbar, the theory of thermal life loss at the temperature of Peter HG ALLEN and Arnold Tustin is required.

2.1. Arrhenius Thermal aging equation

For the thermochemical properties of the polymer material following Arrhenius motel, the chemical reaction rate is closely related to the temperature, and the residual elongation of the thermal aging at constant temperature is determined by equation (1) [3, 10–12]:

$$\ln \frac{E}{E_0} = -Kt\,. \tag{1}$$

Dense busbar trunking is suitable for the power supply and distribution system with AC three-phase four-wire, three-phase five-wire system, frequency of 50∼60Hz, rated voltage to 690V, rated current of 250∼5000A, which is especially suitable for the transformation of old enterprises and the workshop as the auxiliary equipment for power supply and distribution in industrial and mining, enterprises and the high-rise buildings, it is as shown in figure 1. Its characteristics are: (1) phase and phase, phase and splice of dense busbar trunking shall be insulated bolted-up, and adopts the joint of the double connecting copper bar connection to effectively increase the contact area of splice, greatly reduce the junction temperature rise. (2) The conducting bar of dense busbar trunking is winded with flame retardant XLPE heat shrinkable T-bush with strong insulating property, which will not emit toxic gases in case of fire. (3) The socket set of dense busbar trunking interface is flexible and convenient, and it can be equipped with a large number of sockets with strong versatility, and there is no need to change the power supply system when adjusting the position of the electric equipment.

Due to the complex internal structure of insulation life of dense busbar trunking, many kinds of heat transfer medium, the internal temperature distribution of insulation life of dense busbar trunking is also relatively complex, according to vast experimental and operating experience, IEEE C 57 91-1995 gives the empirical model for calculating the winding hot spot temperature, which assumes that the heat loss value caused by unit height of winding is unchanged, so the winding temperature increases linearly along the height and is parallel to the oil temperature that same linearly increases. But its calculation accuracy is poor. Based on the T-S fuzzy model, the calculation model of the top oil temperature of the insulation life of the intensive busbar trunking is proposed in literature [10], which improved the prediction accuracy of winding hot-spot temperature. In this paper, the hot spot temperature calculation is based on the method, and there is no repeat due to the limited space.

Among them, E_0 is the initial elongation percentage, E is percentage of elongation for aged materials, $\frac{E}{E_0}$ is the percentage of residual elongation, $K$is the rate of aging reaction at normal temperature(h^{-1}), t is the aging cycle(h).Have known end extension E_f, Insulation life L. Use(2)to caculate:

$$\ln\frac{E_f}{E_0} = \frac{t}{L}\ln\frac{E_f}{E_0}\,. \tag{2}$$

According to Arrhenius theoretical rate constants:

$$K = K_o e^{-B_i T}\,. \tag{3}$$

Utilize formula(1)and formular(3)to get:

$$\ln\frac{E_f}{E_o} = -LK_o e^{-B/T} \tag{4}$$

For (4) on both sides of the logarithm calculate:

$$\ln L = \frac{B}{T} - \ln K_o + \ln\ln\frac{E_o}{E_f}\,. \tag{5}$$

The final curve can be simplified into Arrhenius curve, B, C is determined by the material itself:

$$\ln L = \frac{B}{T} + C\,. \tag{6}$$

2.2. The theoretical basis of thermal life loss

According to Peter H. G ALLEN and Arnold Tustin [4], the thermal life loss in the case of variable temperature follows:

$$\sum_{i=1}^{n}\frac{t_i}{L_i} \to 1\,. \tag{7}$$

If $\sum_{i=1}^{n}\frac{t_i}{L_i} < 1$, it show that the insulator still has the remaining life; Otherwise it shows that the life of the insulator has been exhausted. In the formula, L_i and t_i respectively indicate the total insulation life and aging time at the operating temperature T_i, $\frac{t_i}{L_i}$ is Insulation loss under temperature T_i, Then in the case of aging time t_i, The total life loss of the insulating material M is:

$$M = \sum_{i=1}^{n}\frac{t_i}{L_i}\,. \tag{8}$$

The operating temperature of the busbar is determined by the ambient temperature and the electricity load. In real life, the ambient temperature and the electricity load of the specific busbar used in fixed occasions have a certain regularity, so the annual working temperature distribution is roughly same, so that the total working life of the busway can be obtained. L:

$$L = \frac{\sum\limits_{i=1}^{n} t_i}{\sum\limits_{i=1}^{n} \frac{t_i}{L_i}}. \tag{9}$$

3. Thermal aging test method

3.1. Accelerated thermal aging test

Polyester film insulating material has two important parameters which are fracture rate and tensile strength. The experimental results show that the elongation at break is much faster than the tensile strength in the accelerated thermal aging test, so the elongation at break is chosen as the experimental parameter. At present, the oven heating method is used to do the thermal aging test method [13-14]. The aging of the busway is rapidly simulated at the high temperature of the oven. According to the research and standard GB / T 13542.2-2009 in the literature [14], the polyester film material should be Select 50% of the end of life, according to IEC60216-2008.2008 [15] radiation cross-linked polyolefin 50% of the original elongation at break as the end of life.The original elongation at break of the polyester film was 98.32%, so the end life point should be 49.16%.

3.2. Accelerated thermal test steps

According to GB / T 7141-2008 ,developed accelerated thermal aging test steps are as follows [16]:

(1)Select the dense busbar polyester film insulation raw material samples, made into a sufficient amount of dumbbells, divided into three groups, each group of samples For 10.

(2)The three groups of samples were placed in the RLH-100 thermal aging test chamber, the temperature point interval should not be too close, according to the standard GB / T 13542.4-2009 temperature selection of 180°, 160°, 140°, in the corresponding conditions Under the accelerated heat aging, take 24h for a sampling cycle interval, the test sample will be taken out 1h after the electronic tensile testing machine for tensile measurement, record each group of samples corresponding to the elongation at break and time.

(3)The test is continued until the test sample reaches the specified end point [17], i.e. near 49.16% of the original elongation at break, the test can be terminated and the corresponding end life time for each group of samples is recorded.

Table 1. Data on accelerated thermal aging tests of polyester film of insulating material of unused busbar

180°		160°		140°	
Aging time/day	The rate of elongation at break/%	Aging time/day	The rate of elongation at break/%	Aging time/day	The rate of elongation at break/%
0	98.32	0	98.32	0	98.32
1	96.11	3	96.15	10	97.57
2	92.54	6	93.98	20	97.01
3	89.17	9	90.55	30	95.04
4	84.33	12	86.72	40	94.11
5	80.22	15	83.11	50	91.25
6	75.31	18	81.01	60	85.17
7	69.19	21	77.55	70	80.19
8	62.53	24	72.83	80	75.33
9	55.78	27	68.75	90	71.75
10	49.20	30	65.99	100	67.52
t	t	33	59.12	110	61.88
t	t	36	50.31	120	56.91
t	t	39	44.77	130	51.11

3.3. Accelerated Thermal Aging Test Data and Its Treatment

In this paper, materials of dense busway which are the used and unused two kinds are tested. In order to facilitate the subsequent expression, the unused polyester film busbar is defined as No. 1 busbar, and the poly The ester film-dense busway is No. 2 busway.

3.3.1. Polyester film aging test results

No. 1 busbar insulation materials to accelerate the thermal aging test data shown in Table 1.

As can be seen from the experimental data in Table 1, the elongation at break will gradually decrease with the aging of the polyester film of No. 1 busway, and the relationship between the degree of thermal aging and the elongation at break is stable and monotonic; 140° elongation at break is the most gentle, close to 49.16% elongation at 130 days to reach the insulation failure standard. At 160 °, the reaction rate is faster than 140°, about 36 days to achieve insulation failure standards; and because the highest temperature at 180 °, the reaction is the most fierce, so the insulation material reach the failure criteria after 10 days.According to the regression analysis method, the relationship between the elongation at break and the time and the curve is obtained by computer. The graph is shown in Fig.1

At the same time, the regression equation of the elongation at break and the aging time at 140°C, 160°C and 180°C are formular(10) - (12):

$$p = -0.5989(\lg t)^3 + 2.1555(\lg t)^2 - 2.5833 \lg t + 2.0018\,. \tag{10}$$

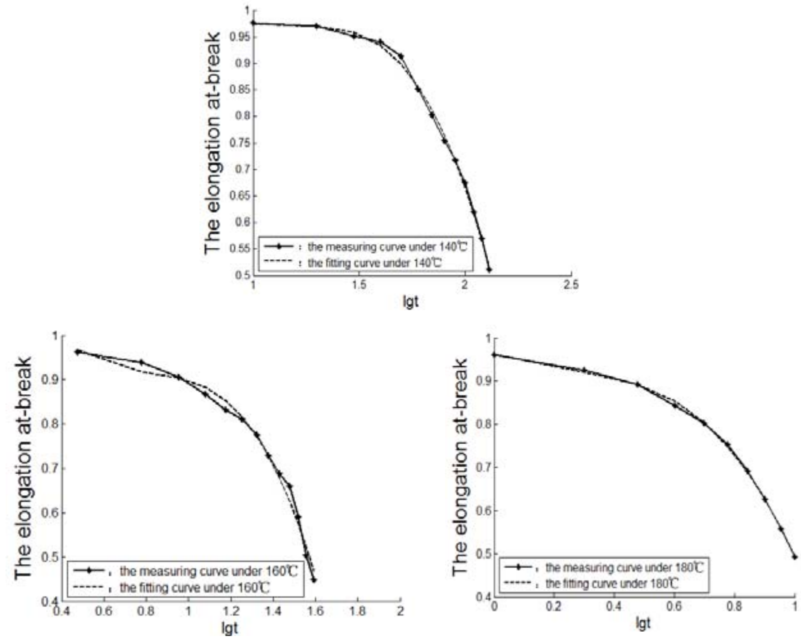

Fig. 1. The relation between aging time and elongation at-break of polyester film under different temperature

$$p = -0.8525(\lg t)^3 + 2.0804(\lg t)^2 - 1.7519\lg t + 1.4225\,. \tag{11}$$

$$p = -0.8271(\lg t)^3 + 0.6059(\lg t)^2 - 0.2468\lg t + 0.9622\,. \tag{12}$$

From the experimental results and calculated that the termination time of the polyester film insulation material at three different temperatures, 50% of the original elongation at break was selected as the termination point, $p = 49.16\%$, Respectively, calculated into the formula (10)-(12), the aging ofthe termination time were: $T_1 = 132.95d$, $T_2 = 37.69d$, $T_3 = 10.04d$.

4. Insulation Life Prediction of Busway

4.1. Thermal Life Equation Calculation of Polyester Film of compact Busway

According to the No.1 busway of the accelerated thermal aging test can be obtained$(T_1, L_1, T_2, L_2, T_3, L_3)$, They are described in Cartesian coordinate systems, discrete distributions in Cartesian coordinate systems, and their fitting curves should be approximated(6). the least squares method is used, by minimizing the square of the error and finding the best fit curve for the data, fit to get B, C, Respectively:

$B = 5.2420 \times 10^3$, $C = -9.1760$.

The Arrhenius equation for the insulation aging of the No. 1 busbar can be obtained as follows:

$$LnL = \frac{5242}{T} - 9.1760 \tag{13}$$

The fitted Arrhenius thermal aging curves are shown in Fig.2

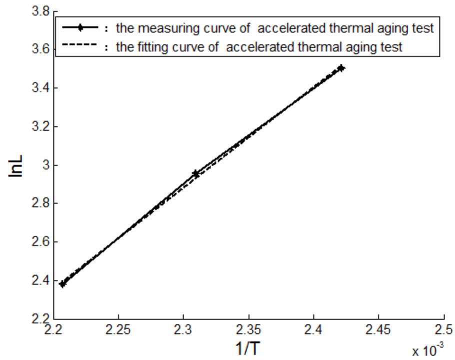

Fig. 2. Thermal aging curve of polyester film busbar

4.2. Temperature data for normal operation of polyester film of intensive busbar

For a long-term use of the building, its surroundings and usedPower has a certain regularity and cyclicity.under normal condition the working temperature of the busway are determined by its electricity load and the surrounding environment, The life prediction is performed based on the surface temperature measurement data of the busbar of the polyester film for one year. Temperature monitoring system was used to measure the surface temperature of the insulating material near a specific polyester film busbar joint for 10 years, and the temperature data was collected every 1 min, so there are 365*24*60=525600 Group data in total for one year, Through statistical analysis, take every 5 degrees Celsius for a temperature interval, get each temperature section of the running time percentage is:

$$A = \frac{n}{N} \times 100\% \tag{14}$$

Among this, n is the number of statistics for each temperature segment and N is the total number of data for the whole year, thereby obtaining the busbar temperature and the corresponding run time percentage as shown in Table 2.

Table 2. The data of surface temperature of copper busbar(polyester film)

Temperature(°)	Run time(%)	Temperature(°)	Run time(%)
5	0.009	50	1.524
10	1.012	55	2.473
15	0.512	60	3.215
20	2.009	65	7.421
25	4.032	70	13.435
30	3.108	75	20.453
35	0.742	80	23.278
40	0.921	85	13.221
45	1.012	90	1.623

4.3. Heat aging equation and thermal life prediction of polyester film of intensive busbar

According to formula(7)and formula(8), Calculate the insulation loss of the cross-linked polyethylene-intensive busbar for 1 year at each temperature. As shown in Table 3, the life loss at different temperatures is added to obtain the total thermal life loss of the No. 1 busbar:

$$M = \sum \frac{t_i}{L_i} = 1.2734\% \tag{15}$$

So, use$L = \frac{1}{M}$, to get $L = 78.53a$.

5. Life prediction of used dense busway

The dense busway used here is exactly the same as the corresponding new compact busbar model, which is the same type of old and new polyester film busbar; the old and new radiation cross-linked polyolefin busbar models are the same. Take the No. 2 busway insulation material as a sample and perform an accelerated thermal aging test in accordance with the accelerated thermal aging method described in Chapter 2 with an elongation at break of 49.16% as the insulation failure end point of the used polyester film insulation , When the test to the insulation failure, then stop the test, and record the relevant data, accelerated thermal aging test elongation at break and the relationship between the time shown in Table 3.

Table 3. Accelerated thermal aging test data of insulating material of used polyester film busbar

180°		160°		140°	
Aging Period/day	The rate of elongation at break/%	Aging Period /day	The rate of elongation at break/%	Aging Period/day	The rate of elongation at break/%
0	95.65	0	95.65	0	95.65
1	93.57	3	94.12	10	93.99
2	90.21	6	92.39	20	91.54
3	85.73	9	90.17	30	87.23
4	82.85	12	86.23	40	85.10
5	75.19	15	82.11	50	82.45
6	69.22	18	77.33	60	77.69
7	65.63	21	70.13	70	74.57
8	57.11	24	62.37	80	70.33
9	49.20	27	57.21	90	65.58
t	t	30	51.14	100	59.74
t	t	33	45.12	110	56.28
t	t			120	49.31

Using the same method as the No. 1 busway, the relationship between the elongation at break and the aging time was obtained by computer fitting,:

$$p = -0.6786(\lg t)^3 + 2.6256(\lg t)^2 - 3.4672 \lg t + 2.4630\,. \tag{16}$$

$$p = -0.7562(\lg t)^3 + 1.5289(\lg t)^2 - 1.0640gt + 1.1833\,. \tag{17}$$

$$p = -0.7979(\lg t)^3 + 0.4992(\lg t)^2 - 0.2072gt + 0.9365\,. \tag{18}$$

According to formula(16)-(18), Calculate the result that 2 busbar heat aging end life respectively: $t_1 = 120.73d$, $t_2 = 30.87d$, $t_3 = 9.12d$ under 140°, 160°, 180°. Deduced Arrheniusformula:

$$\ln L = \frac{5247.8}{T} - 9.2462\,. \tag{19}$$

The insulation life at different temperatures is calculated by formula (19), and then the insulation life is calculated as 69.41a with the same method as for calculating the insulation life of busbar No. 1, and it is already used 10a, then the overall insulation of the busbar Life expectancy is 79.41a, which is basically the same as the 78.53a obtained from the No. 1 busbar.Insulation life loss of power dense busbar trunking

6. Conclusion

In this paper, the same type of material used in the same type has not been used with the intensive busbar for life prediction. First, based on the operating temperature of a corresponding year of the material busbar, the unused polyester film busbar was predicted to be 78.53a and the used busbar life was 79.41a Compared with the two sets of data available, the same type of material for the same type of busbar, before and after the use of the total life expectancy is basically the same, so this method is feasible. Compared with the actual temperature (often the maximum allowable working temperature) to predict the insulation life of electrical equipment, this theory of combined thermal life loss prediction method is more close to the actual situation, the forecast will be relatively accurate.

Because this method is based on the actual operation of the intensive busbar temperature data on the basis of its insulation life prediction, so the method can be used for electricity with the law of the strong residential buildings, factories, substation-intensive bus , Also applies to other types of busway (the busbar insulation material thermal life consistent with the Arrhenius equation) life prediction, the cable life prediction is also applicable. At the same time the method also has some limitations, first of all, for the regularity of the load is not strong or the surrounding environment in the ever-changing electrical equipment, the method of forecasting will be inaccurate; because the method requires on-line monitoring system to provide more temperature data , There is no measured temperature of the electrical equipment, this method has limitations.

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