A Novelty Method Subjectif of Electrical Power Cable Retirement Policy

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ABSTRACT

An age data of the same type cables under the same operation condition in a regional transmission system was collected. Use a probability analysis method and the age data to calculate the reliability functions of normal distribution and Weibull distribution, which reflect the reliability level of cables. Effect Analysis system Failed mode (EAFM) is applied to find the characteristic fault parameters, which contribute to the cable failure and can be obtained by the preventive tests. Fuzzy membership function is constructed to estimate the failure probability. Fuzzy analytic hierarchy process (AHP) is employed to define the importance weight of failure mode, and the reliability value of the cable will be gained through the weighted average method. It is estimated by using the reliability function and the cable reliability value that the expected damage cost (EDC) of the transmission system is caused by cable failure. The interest income can be gained by delaying the retirement of the aging cable. Finally, an appropriate time of the cable retirement is found when making an economic comparison between the EDA and the interest income due to the retirement delay.

Keywords : -aging cable; retirement policy; reliability; expected damage cost; interest income

1. INTRODUCTION

At present, cables have been widely used in urban transmission and distribution system in China. For example, cable has accounted for 40% of the length of the transmission line in Shanghai (Solly Aryza etall, 2018). However, cable's fault diagnosis and localization are more complex and challenging than overhead line due to laying on the ground and sufferin(Solly Aryza,etall, 2017) from the moist environment. Preventive test of a single characteristic parameter, or sampling a section of cable doing preventive tests of multiple settings is difficult to quantify the reliability of the cord .

XLPE cable has been developed and used in China for nearly 40 years. The insulation of some cable has aged severely, which has a potential risk on the normal operation and safety of the power grid due to unexpected cable failure. The aging progress of the cable is caused by some defects such as impurities, protrusions, voids and semiconducting screen roughness brought about by manufacturing process [3].

Under the high electric stress of electric field, these defects may develop into water trees or electrical trees. When electrical trees or water trees run through the cable insulation, it can lead to a complete dielectric failure at any time.

Two methods are widely applied in reliability assessment of cable.Probability analysis method. The cable reliability Functions can be established by using the Weibull distribution and normal distribution. The parameters of two distributions are evaluated based on the historical data of cable failure and age.

EAFM method. According to failure mechanism and effect analysis, the comprehensive evaluation method of cable failure probability can be established based on the fuzzy membership degree. The functions of fuzzy membership degree can be constructed by using characteristic parameters of cable, which are obtained by the preventive testing. The two methods are combined to evaluate the reliable age of cable in this paper. The EDC which is caused by the failure of aging cable is quantified by economic theory. The retirement time of the wire can be determined eventually by comparing the EDC and the investment interest due to the retirement delay.

2. THE PROBABILITY ANALYSIS METHOD

The reliability functions can be estimated based on Weibull distribution and normal distribution. The method contains the following two steps [4, 5].

Prepare aging data of the same type cables under the same operating condition. The majority of equipment is in operation and only the in-service year is needed. For previously retired equipment, both the in-service and retired years are needed. At present, cables have been widely used in urban transmission and distribution system in China. For example, cable has accounted for 40% of the length of the transmission line in Shanghai [1]. However, cable's fault diagnosis and localization are more complex and challenging than overhead line due to laying on the ground and suffering from the moist environment. Preventive test of a single characteristic parameter, or sampling a section of cable doing preventive tests of multiple settings is difficult to quantify the reliability of the cord [2].

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Reliability function establishing.Equation is the reliability function of normaldistribution. In fact, there is no explicitly analytical expressionfor the function. Reference [5] gives the polynomialapproximation.

$$R(t)=1-\int_{-\infty}^{x}\frac{1}{\sigma\sqrt{2\pi}}\exp\left[-\frac{1}{2}\left(\frac{(x-\mu)^2}{\sigma}\right)\right]dx$$

(1)

Where t is the age year of the cable; f1 and (J are mean life and standard deviation respectively; R(t) is the reliability of the cables. Equation (2) is the reliability function of two parameters Wei bull distribution.

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Table 1. Type Style Of Cables

Failure Mode	Impact Analysis	The Characteristic Parameters of Aging Failure	Alarm Value
Insulation Breakdown	Aging failure of cable is non-repairable, only replacement can reduce risk of aging failure. The replacement may cost a long time, which increase the risk of power grid operation	Y1: Insulation Resistance	>1000MΩ/ m
		Y2: Dielectric Loss Tangent	<1%
		Y3: PD	<10pC

With the increasing of aging degree, the parameters, Yl (Dielectric Loss Tangent) will decrease, and Y2 (Insulation Resistance) and Y3 (PD) will increase. Two kinds of fuzzy membership functions are established and adopted to describe the failure probability of three parameters Yl, Y2 and Y3.

Equation (3) is structured when the value of the parameterhas a lower limit alarm value b, Such as the alarm value of Yl

is upper than 1000 MQ/m.

$$\mu_b(x)=0.5-0.5\left[\sin\frac{\pi}{2b}(x-b)\right]$$

(2)

Using the value R and two functions given in Section II, thereliable life of the cable is calculated by inversion calculation. It is important to note that the reliable life is always different from the physical life. Considering the difference of operation condition, the aging rate of each cable are different, which makes the difference between reliable and physical life. However, the reliable life shows more accurate than physical life to reflect the reliability level and degradation condition of the cable.

3. ECONOMIC COMPARISON AND RETIREMENT ANALYSIS

Delaying retirement of aging cable is increasing thepossibility of power system interruption and the damage cost. However, retirement of aging cable needs large numbers of funds to invest in retirement process, including the elimination of the aging cable, the purchase, transportation, installation and commissioning of the new cable. The interest income can be gained by delaying the retirement. The detailed estimation process of the interest income is showed as following.

Setting the reference year, then the economic

comparison can be expressed in (5) by using the

criterion of the minimum i

$$EDC_i > A_i\,,\quad i=1,2,3\ldots N$$

.

(3)

Where i is the operation year after the reference year, the inequality indicates that the EDC in the ith year is larger than the interest income Ai in the ith year by retirement delay, which means the cable should be replaced in the ith year to achieve the maximum economic benefits.

$$F_f = \sum_{i=1}^{N} F_{fi} \cdot UD_i$$

$$F_{fi} = \frac{\int_T^{T+i\Delta t} f(t)\,dt}{\int_T^{\infty} f(t)\,dt} = \frac{R(T+i\Delta t) - R\left[T+(i-1)\Delta t\right]}{R(T)}$$

(4)

Where UDi =1-(2i-I)·L1tI2; i is an integer between I to N; M=tIN, N is an integer; R(t) is the reliability function motioned in section II; T is the survived year. t= I a in the model; The unavailability FJ can be sufficiently accurate estimated when N is large enough.

Where r is the interest rate; V is the total capital investment of the replacement, which includes the elimination of the aging cable, the purchase, transportation, installation and commissioning of new cable.

4. EXAMPLE AND ANALYSIS

The failure statistics data of 35 kV cables in a certain area are shown in Table III. In 2013, the GDP in this area was 436.09 billion yuan, the whole electricity consumption was 39.089 billion kWh [8]. The total number of 35 kV level transmission lines is 3440, the annual capital investment of a 35 kV cable line in this area was estimated to be 500 000 yuan with the interest rate of 5%. tc =24h.

Tables 2. Cables Data

NO.	In-service Year	Age	NO.	In-service Year	Age
1	1972	41	11	1999	14
2	1974	36(Retired)	12	2000	13
3	1974	39	13	2002	11
4	1978	31(Retired)	14	2004	9
5	1982	30(Retired)	15	2007	6
6	1993	20	16	2007	6
7	1996	17	17	2008	5
8	1997	16	18	2009	4
9	1997	16	19	2010	3
10	1999	14	20	2011	2

Table 2 shows the age and survival probability of thecables. The mean life and standard deviation of normal distribution are 11 =34.6422 and 0-=2.4093. The parameters of Weibull distribution optimization should be carried out first by using the gradient descent method and the scale and shape parameters are estimated as a =33.9146 and j3 =9.0044.

Plotting two kinds of reliability functions in the samecoordinate graphic, shown in Fig.l. Combined with the age and failure data shown in Table 2, the cables which retired have survived more than thirty years. Therefore, the reliability function based on normal distribution is chose to calculate the

unavailability of the aging cable for its higher accurate than Weibull distribution.

Tables 3. Data Used In The Estimation

Age	Cumulative Failure Probability	Survival Probability
29	0.001	1
30	0.201	0.799
31	0.451	0.549
36	0.784	0.216
41	0.784	0.216

The values of fault characteristic parameter Y I, Y2 and Y3are showed in Table V. The weight vector for three parameters is also given by using AHP and also showed in Table V. Itshould be mentioned that all the other equipment such as bus lines, electric generators or transformers should be assumed to be 100% reliable in this model since their failures may not have effects on the EDC.

The aging failure probability of the cable is 0.0657 afterassessment and the reliability R is 0.9343. The reliable life of the cable is 31 a evaluated by (1).

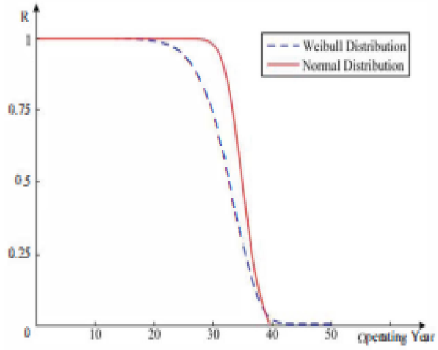

Figure 1. The curves of reliability functions based on Weibull and nonnal distribution.

Tables 4. The Preventive Test Data.

Project	Test Data	Degree of Membership	Weight
Y1 Insulation resistance	1540MΩ/m	0.1249	0.25
Y2 dielectric loss tangent	0.04%	0.1379	0.25
Y3 PD	not detected	0	0.5

The unit interruption cost b is 11.2 yuan/kWh aftercalculation from the data. C is 5 200 000 kWh/year, which calculated after setting all the 35 kV power transmission lines in parallel operation and their transmission of electricity is same with each other. The Ff is calculated by (7), the estimated values of EDC and Ai from different years since 2014 to 2017 are showed in table V.

Tables 5. The Result Of All Index

i	Year	F_f	EDC (in yuan)	A_i (in yuan)
1	2014	0.0243	8470	25000
2	2015	0.0435	15170	26250
3	2016	0.0760	26500	27563
4	2017	0.1282	44700	28941

According to the result, the EDC of this cable in 2016 willbe larger than the capital investment interest income.

Therefore, this cable should be retired and replaced in 2016 toensure the safety and economy of the power system.

5. CONCLUSION

The retirement decision method of cable is presented in this paper. This method can gives an appropriate time of the cable retirement by comparing the EDC with the interest income due to the retirement delay. The EDC is estimated by

using the reliability function and the cable reliability value. The reliability functions are based on Weibull distribution and normal distribution. The parameters of two functions are

evaluated by analyzing the historical failure data and the aging data of same type cables.

The cable reliability value is calculated by a comprehensive evaluation model. In this model, the fault characteristic parameters are chosen through FMEA method; the failure probability is calculated by the fuzzy membership function based on the preventive test data of each parameter; the importance weight of each parameter is quantified by AHP.

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