한국조명•전기설비학회 2007춘계학술대회 논문집(2007.5.10~11)

배전기기 고장률 추출에 관한 연구

A Study on Failure Rate Extraction of Power Distribution System Equipment

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Abstract

In this paper, the Time-varying Failure Rate (TFR) of power distribution system equipment is extracted from the recorded failure data of Korea Electric Power Corporation (KEPCO). For TFR extraction, it is used that the fault data accumulated by KEPCO during 10 years. The TFR is approximated to bathtub curve using the exponential (random failure) and Weibull (aging failure) distribution function. In addition, Kaplan-Meier estimation is applied to TFR extraction because of incomplete failure data of KEPCO. Finally, Probability plot and regression analysis is applied. It is presented that the extracted TFR is more effective and useful than Mean Failure Rate (MFR) through the comparison between TFR and MFR.

1. Introduction

The extraction of accurate failure rate is essential for more accurate reliability evaluation. If the failure rate according to time is predicted and the predicted failure rate is accurate, the trend of reliability indices can be evaluated through the current and future reliability evaluation of real power system. If the evaluated reliability index is accurate, then we can know how the reliability indices will change at several years later, which region have the weak reliability indices and which components are affecting the reliability indices adversely. Consequently power system investment plan and power system asset management can be possible.

In this paper, the TFR is extracted from real recorded failure data for 10 years of KEPCO using exponential and Weibull distribution function. First, the recorded fault data and fault cause is analyzed. Next, the TFR is approximated to bathtub curve using the exponential and Weibull distribution function expressing the random failure and aging failure, respectively. Also, the Kaplan-Meier estimation is used for adjusting the different operation-starting time of each component. Finally, The probability plot and regression analysis is applied to TFR extraction. At conclusion, the extracted TFR of power distribution system equipment is presented.

2. TFR Extraction Method

The procedure of TFR extraction including the scope of population and failure cause analysis is presented at Fig. 1. That is, If the failure is random one, the MFR is extracted from operating time and the occurred failure time. Otherwise, If the failure is aging failure, the TFR is extracted from parameters of Weibull distribution function through the cumulative failure probability and regression analysis.

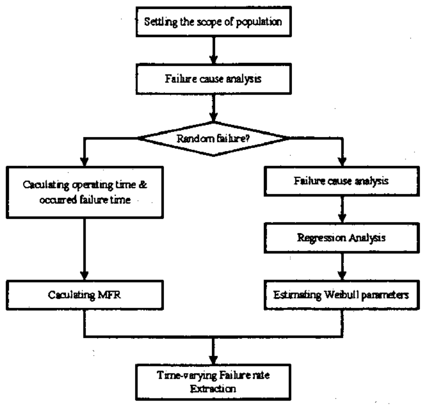

Fig. 1. The procedure of TFR extraction

2.1 Random failure data analysis

The Maximum Likelihood Estimator(MLE) of failure rate is given by eq. (1)

$$\hat{\lambda} = \frac{r}{\sum_{i \in Z_1} t_i + \sum_{i \in Z_2} t_j} \tag{1}$$

where r is the number of random failure occurred, t_i is the operating time of faulted equipment, t_j is operating time of normal equipment, and Z_1, Z_2 are the set of faulted and normal equipment, respectively.

As a result, the calculated random failure rates for each distribution system equipment are represented at Table 1.

Table 1. Analysis results of random failure

Equipment	Mean Time of Random Failure for 10 years [year]	Sum of Estimated Failure Time [year]	Estimated Normal Operating Time [year]	Sum of Operating Time [year]	Random Failure Rate [freq./year]
Overhead Conductor Wire	8.25	137,593.5	16.5	5,774,604.0	2.82E-03
CNCV Cable	7.74	18,630.2	15.1	233,686.1	9.54E-03
Interrupter Switch	10.82	7,974.3	14.5	49,880.0	1.27E-02
Line Post Insulator	9.45	14,609.7	11.5	197,651,351.0	7.82E-06
Suspension Insulator	8.12	61,720.1	16.0	1,323,401,807.3	5.74E-06
Cut Out Switch for TR	7.68	30,750.7	14.0	44,725,002.0	8.95E-05
Cut Out Switch for Line	7.61	5,669.5	12.5	3,293,830.5	2.26E-04
Assembling type of Joint Kit	7.04	309.8	11.6	4,029,143.6	1.09E-05
Assembling type of Termination Kit	7.44	238.1	10.7	1,249,717.3	2.56E-05

2.2 Aging failure data analysis

The procedure of aging failure rate analysis is as following:

1) Acquisition of data
2) Rank of data
3) Kaplan-Meier estimation (*see* 2.3)
4) Weibull probability plot (*see* 2.4)
5) Analysis of Weibull probability plot using regression analysis (*see* 2.4)
6) Estimation of Weibull parameters (*see* 2.4)
7) Calculation of aging failure rate

2.3 Kaplan-Meier Estimation

For drawing the Weibull probability plot, the data should be ranked from low value to high value of failure time, the PDF of each case be estimated and the trend line be estimated. Also, we can recognize the results of TFR are good or bad through examining the goodness of fit.

Because operation-starting time of equipment is different with each other, Kaplan-Meier estimation is used to estimate the PDF. where r_i is the inverse order value of i-th fault data and R_0 is equal to 1.

$$R_i = [(r_i - 1)/r_i] \bullet R_{i-1} \tag{2}$$

The results are represented at Table 2. Because the fault data exist for only 10 years and are not sufficient to estimate the failure rate, eq. (2) is modified like eq. (3)

$$R_i = \left[\frac{r_i - [1/(p_1 \times p_2)]}{r_i}\right] \tag{3}$$

where p_1 is data ratio for analysis, that is, the number of aging failure data divided by the estimated number of aging failure in population. p_2 is the fault reporting ratio. It needs to revise the omitted report because of human error, so on.

Table 2. The number of equipment set up and the data ratio for analysis

	The number of Available Data	The Estimated Number of Set-up Equipment During a month	Data ratio for Analysis (p_1)
Overhead Conductor Wire	216	925	0.18
CNCV Cable	292	49	0.24
Interrupter Switch	42	12	0.14
Line Post Insulator	428	62277	0.30
Suspension Insulator	770	214299	0.21
Cut Out Switch for TR	186	9519	0.14
Cut Out Switch for Line	57	875	0.18
Assembling type of Joint Kit	61	1242	0.42
Assembling type of Termination Kit	10	457	0.43

2.4 Weibull Parameters Estimation

The horizontal and vertical axis of Weibull probability plot is natural log value of life time t, and the modified cumulative probability of faulted equipment until time t, respectively.

$$\ln \ln[1/(1 - F(t))] = m \ln(t) - m \ln(\eta) \tag{4}$$

Above eq. (4) is a form of first order function. Thus the parameters can be estimated from the trend line extracted from regression analysis. The shape parameter, m, is the slope of the trend line, the scale parameter, η, is represented to $\exp(-k/m)$, where k is a intercept of y. The result of regression analysis for OC wire is showed at Fig. 2.

Also, the Mean time to failure (MTTF) can be calculated if Weibull parameters are estimated. The calculated Weibull parameters, MTTF, and aging failure rate per year for each equipment is represented at Table 3.

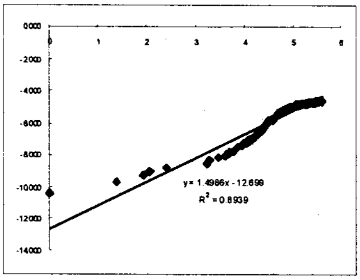

Fig. 2. The result of regression analysis for OC wire

Table 3. Weibull parameters, MTTF, and aging failure rate per year

	Shape Parameter	Scale Parameter	MTTF[year]	Mean Aging Failure Rate [/year]
Overhead Conductor Wire	1.50	4787.09	360.17	2.78E-03
CNCV Cable	2.55	396.70	29.35	3.41E-02
Interrupter Switch	2.47	344.76	25.48	3.92E-02
Line Post Insulator	2.41	5640.17	416.68	2.40E-03
Suspension Insulator	2.91	3235.59	240.47	4.16E-03
Cut Out Switch for TR	2.28	3210.93	237.03	4.22E-03
Cut Out Switch for Line	1.58	6927.55	518.14	1.93E-03
Assembling type of Joint Kit	1.68	10090.96	750.96	1.33E-03
Assembling type of Termination Kit	1.10	165378.44	13280.96	7.53E-05

3. The Results of TFR Extraction

The final time-varying failure rate function is represented to the sum of random failure and aging failure rate function. The expected number of failure occurred to a specific point of time for each equipment is estimated from integral calculus of failure rate function. Thus, failure rate per year is the value subtracted the integral value at one year ago from a specific time from the integral value at a specific time and extracted TFR is represented at Fig. 3. The constant line at graph is MFR, which is calculated from the number of fault divided by recording duration. And the increasing line at graph is extracted TFR using exponential and Weibull distribution function.

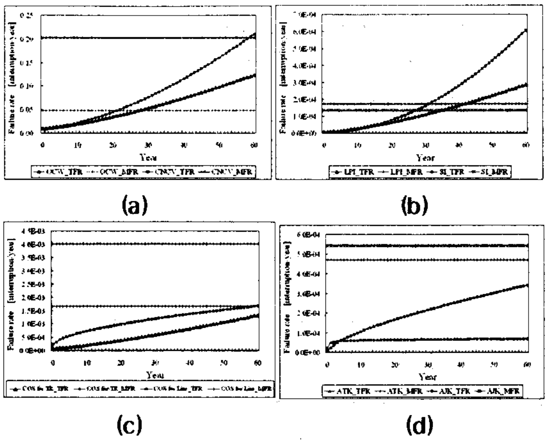

Fig. 3. TFR of distribution system equipment

4. Conclusions

In this paper, the time-varying failure rate was extracted to a form of bathtub curve using probability distribution functions from real accumulated fault data of KEPCO for 10 years.

The fault data was classified into random and aging failure according to fault management codes of KEPCO, the former is estimated using exponential distribution function with memoryless property and the later estimated using Weibull distribution function used most generally for aging failure. Through the comparison of MFR and TFR at results, it is proved that TFR is more accurate and realistic for failure rate evaluation.

This work has been supported by KESRI, which is funded by MOCIE(Ministry of commerce, industry and energy

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