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Estimation of Power supply Lifetime in NPP's Environment

Pil Ju Lee, Sang Yong Lee, Jin Kang Kim, Myoung Yoon Kim, Tae Wan Kim
PONUTech Co. LTD., R&D Center Reliability Analysis Team
#974-1, Goyeon-ri, Woongchon-myun, Ulju-gun, Ulsan, South Korea, 689-871

1. Introduction

The I&C system used in nuclear power plant (NPP) power is supplied by numerous power supply (PS). Therefore, power supply is very important equipment for NPP's safety and reliability. In this paper, we estimate power supply lifetime, probability method (failure distribution analysis, Weibull) and the physical method (accelerated lifetime data, Telcordia III). In addition, we performed sensibility analysis for power supply lifetime.

2. Estimation of PS Lifetime By Telcordia Methods

We applied Telcordia method in order to estimate the lifetime of the power supply considering accelerated life data and operation environment. At first, we estimated the failure rate of the power supply by Telcordia method I. [1]

Telcordia method I equation for failure rate estimation of Power supply is as follows.

$$\lambda_{SSM} = \pi_E \times \sum_{i=1}^{n} N_i \lambda_{SSi} \qquad (1)$$

where

λ_{SSM} = Failure rate of steady state

π_E = Environmental factor,

N_i = Allogeneic parts number

λ_{ssi} = Failure rate of individual parts

$(\lambda_G \times \pi_Q \times \pi_S \times \pi_T)$

The failure rate of the power supply is 3.07E-6 calculated from equation (1). The applied factor and component failure rate used general data.

Telcordia method III equation is as follows. The failure rate value (λ_{pc}) is calculated from Telcordia I

$$\lambda_{ss} = \frac{2+f}{\frac{2}{\lambda_{SSM}} + (V \times t \times 10^{-9})} \qquad (2)$$

where

λ_{ss} = The failure rate of the evaluation system

λ_{SSM} = Failure rate of the steady-state

V = Correction factor, t = Total operation time

f = The number of failures that occurred in the field

When applying analyzed parameter (failure rate (3.07E-6), failure number (2), operation time (221,352h), V (1) substitute into equation (2), the equation (3) is as follows.

$$\lambda_{ss} = \frac{2+2}{\frac{2}{3.07E-6} + (1 \times 221{,}352 \times 10^{-9})} = 6.14E-6 \qquad (3)$$

Therefore, the average lifetime of the power supply was calculated as about 19 years. We checked that this result value is identical with Relex(reliability analysis program) output value. The sensitivity of lifetime for change of failure number is as follows.

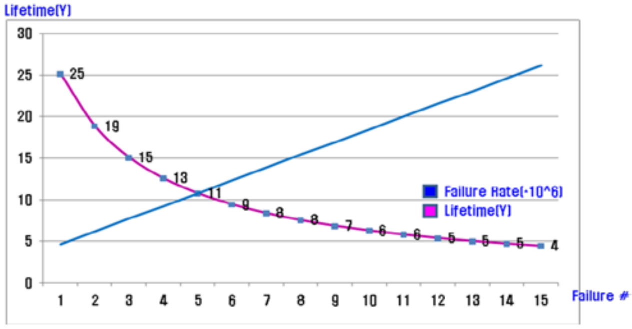

Figure 1. Sensitivity Analysis for Lifetime

3. Estimation of PS lifetime By Weibull Distribution

We investigated replacement history of domestic and foreign NPP in order to estimate the lifetime of the power supply by a probabilistic method. And no-failure period, failure period, lifetime after installation required to lifetime estimation could be obtained as shown in the table below based on the survey results

Table 1. Quantification of failure data for life estimation

Survival period	Failure checking	Popu lation	Survival period	Failure checking	Popu lation
6	No failure	3	201	No failure	5
18	No failure	2	242	Failure	1
18	No failure	2	261	Failure	2
18	No failure	5	267	No failure	1
80	No failure	5	280	No failure	2
89	No failure	5	295	No failure	5

108	No failure	5	297	Failure	1
115	No failure	5	302	Failure	1
144	No failure	2	304	No failure	5
147	No failure	5	308	No failure	4
161	No failure	2	315	No failure	4
162	No failure	2	326	Failure	2
162	No failure	1	335	Failure	1
174	No failure	2	341	No failure	2
192	No failure	5	386	Failure	1

Power supply was inspected periodically and replacement reasons shown below mainly.

√ Obsolescence of power supply component parts
√ Aging of power supply
√ Excessive drifts causing low accuracy and precision

The Weibull distribution is useful in many reliability works since it is a versatile distribution. By adjusting the distribution parameters, it can approximate a wide range of life distribution characteristics for various many devices. [2]

The Weibull density function is (4):

$$f(t;\alpha,\beta) = \frac{\beta}{\alpha}\left(\frac{t}{\alpha}\right)^{\beta-1} \exp\left[-\left(\frac{t}{\alpha}\right)^{\beta}\right], \qquad (4)$$

where
β : the shape parameter,
α : the scale parameter.

The likelihood function for given times $t_1, t_2, \cdots, t_n$ is (5):

$$L(\alpha,\beta) = \prod_{i=1}^{n}\left[\frac{\beta}{\alpha}\left(\frac{t_i}{\alpha}\right)^{\beta-1}\exp\left[-\left(\frac{t_i}{\alpha}\right)^{\beta}\right]\right]^{\delta i}\left[\exp\left[-\left(\frac{t_i}{\alpha}\right)^{\beta}\right]\right]^{1-\delta_i}, \qquad (5)$$

where $\delta_i = 1$ or 0 according to t_i is a failure time or a censored time.

Then, log-likelihood function is (6):

$$\log L(\alpha,\beta) = \sum_{i\in F}\log\beta - \sum_{i\in F}\beta\log\alpha + \sum_{i\in F}(\beta-1)\log t_i - \sum_{i=1}^{n}\left(\frac{t_i}{\alpha}\right)^{\beta} .(6)$$

Where F means the set of failure times

If the number of time belonging to F is r, (6) becomes (6):

$$\log L(\alpha,\beta) = r\log\beta - r\beta\log\alpha + \sum_{i\in F}(\beta-1)\log t_i - \sum_{i=1}^{n}\left(\frac{t_i}{\alpha}\right)^{\beta} .(7)$$

Putting the partial derivatives of (7) with respect to α and β to 0, we get (8) to compute two MLE's of $\hat{\alpha}$ and $\hat{\beta}$:

$$\frac{\sum_{i=1}^{n} t_i^{\hat{\beta}}\log t_i}{\sum_{i=1}^{n} t_i^{\hat{\beta}}} - \frac{1}{\hat{\beta}} - \frac{1}{r}\sum_{i\in F}\log t = 0,\quad \hat{\alpha} = \left(\frac{1}{r}\sum_{i=1}^{n} t_i \hat{\beta}\right)^{\frac{1}{\hat{\beta}}}, \qquad (8)$$

MTBF is then computed as (9):

$$MTBF = \hat{\alpha}\Gamma(1+\frac{1}{\hat{\beta}}), \qquad (9)$$

Newton-Raphson numerical method is used to find two MLE's of α and β and then MTBF. Computer program is as follows.

```
x_n_1 = int_VAL

Do

    k = k + 1 'do loop counter

    f_x = Maximum_LikeHood_F(int_VAL, t_CNT, f_SUM, f_CNT) 'function
    df_x = Dis_Maximum_LikeHood_F(int_VAL, t_CNT)  'differential

    x_n = x_n_1 - f_x / df_x 'newton method, beta cal

    If Abs(x_n - x_n_1) < err_lim Then Exit Do

    int_VAL = x_n
    x_n_1 = x_n

Loop

alpa_V = alpa_VAL(x_n, t_CNT, f_SUM) ^ (1 / x_n) 'alpa cal

MTBF = alpa_V * Exp(1 + GammaLn(1 / x_n))
```

Figure 2. MTBF estimation program source

Parameters and lifetime tables that occur in the course of program execution is given in the table below.

Table 2. Calculation results for Parameters and lifetime

Initial	Beta	Alpha	MTBF
1.14E+01	1.14E+01	3.59E+02	2.86E+01
x_n_1	f_x	df_x	x_n
1.0000000	-1.3192474	1.2159047	2.0849924
2.0849924	-0.6368848	0.3346262	3.9882646
3.9882646	-0.2837501	0.1013590	6.7877194
6.7877194	-0.1151716	0.0365864	9.9356510
9.9356510	-0.0293791	0.0214281	11.403035
11.306702	-0.0018256	0.0189505	11.403035
11.403035	-0.0000067	0.0188127	11.403389

4. Conclusion

In this paper, the power supply lifetime was estimated in two methods. The first method is accelerated life data of electronic components and field failures, the operation environment, etc. In addition, sensitivity analysis of the lifetime is as follows when changing failure number.

In the second method, we calculated the lifetime by applying probability distribution (Weibull) based on the replacement history of the domestic and foreign NPP power supply. The lifetime was calculated about 29 years.

REFERENCES

[1] Telcordia, Reliability Prediction Procedure for Electronic Equipment(SR-332), Telcordia Technologies, Issue 1, 2001
[2] MIL-HDBK-338B, "Electronic Reliability Design Handbook", Department of Defense, 1988.