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Optimum Replacement Cycle of DC High-Speed Circuit Breaker Parts

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Abstract: The replacement cycle of the equipment is usually decided by the technical specification provided by its manufacturer. However, it may vary according to the usage environment of equipments. Therefore, accumulated failure history of equipments in the field is important to determine their lifespans. In case equipments are deployed in many sites it is not hard to gather enough failure data in a short period of time. On the other hand, the equipment installed in a very limited industrial field requires a long period time to acquire the sufficient amount of accumulated failure data. In this study, we aim to analyze an optimal replacement cycle of three types of parts used in DC high speed circuit breaker using a statistical analysis based on the fault history. The results can be applied to set up an efficient maintenance plan to reduce the unnecessary labor and cost.

Key words: Circuit breaker, replacement cycle, failure history, cost-effective analysis, inspection process, lifespans

INTRODUCTION

The DC high-speed circuit breaker is used in the limited industrial fields such as urban railway and steel mill. It is composed of various parts which require a complicated maintenance procedure. In case of urban railway, the lifespan of parts in the DC circuit breaker can be shortened due to the vibration, dust and heat. Therefore, a detailed maintenance strategy and consideration of the life expectancy of parts are required to guarantee an efficient maintenance of the DC circuit breaker.

The maintenance process can be divided into the inspection process and the replacement process. The replacement process is defined as the procedure of replacing the equipment or part based on the level of its deterioration or failure (Kim and Ji, 2016). For the inspection process in case this stage takes too much time, it will be more difficult to repair equipments due to the late detection of failure. Moreover, it may lead to an unnecessary replacement of equipments. On the other hand, if the inspection period is shortened, more manpower is required due to the frequent inspection. Therefore, the cost-effective analysis should be carried out before the replacement process begins.

The failure of equipment or part which is not replaced at the right time could cause the failure cost. If the operating time increases, the probability of failure and the failure cost are likely to increase. On the other hand, the prevention cost decreases since the replaced equipments do not need an additional maintenance. The optimal replacement cycle is obtained where the total cost including failure cost and prevention cost is minimized (Kim and Yoon, 2011).

MATERIALS AND METHODS

Optimum replacement cycle: The total cost per one cycle of the equipment replacement C_{CYCLE} can be expressed as follows (Kang and Kang, 1992):

$$C_{CYCLE}(t) = \frac{C_p.R(t)+C_u.[1-R(t)]}{\int_0^t R(s)ds} \quad (1)$$

Where:
C_p = The prevention cost
C_u = The replacement cost
$R(t)$ = The reliability of equipment or part at time t

The numerator of Eq. 1 indicates an expected total replacement cost per lifespan cycle and the denominator indicates an estimated lifespan cycle. The optimal replacement period T_{opt} is the time t which satisfies in Eq. 2:

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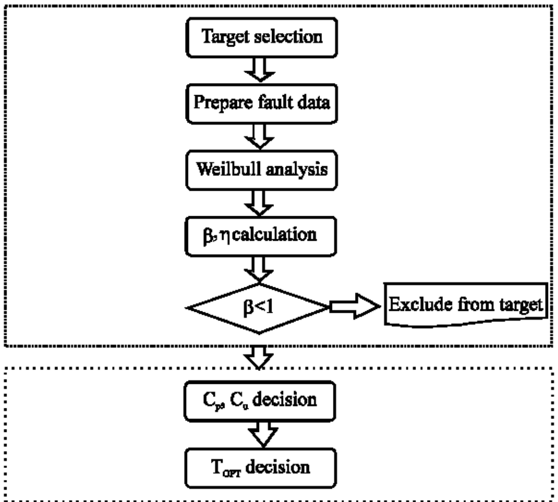

Fig. 1: Decision procedure for optimal replacement period

$$\frac{\partial[C_{CYCLE}(t)]}{\partial t} = 0 \quad (2)$$

In order to obtain T_{OPT}, R(t) of the equipment needs to be calculated. It is necessary to identify the probability distribution of the failure time from the failure data to calculate R(t). The failure time distribution is assumed to be the Weibull distribution which is generally used in the failure analysis. The decision procedure of optimal replacement cycle is shown in Fig. 1.

RESULTS AND DISCUSSION

The Weibull distribution is used to estimate the optimal replacement period of three parts in DC high speed circuit breaker. The Weibull distribution is generally used for the reliability analysis and the 3 parameter Weibull distribution is mainly used. Among 3 parameters of this distribution, the location parameter could cause a difficulty in parameter estimation, so, it is generally assumed to be zero. In this experiment, 2 parameter Weibull distribution without the location parameter is used instead of 3 parameter Weibull distribution. The shape parameter β determines the shape of the distribution. The scale parameter η specifies the scale of the horizontal axis. The parameter values are calculated by Maximum Likelihood Estimation (MLE) method (Lee and Lee, 2016; Shanmugan and Breipohl, 1988).

In this study, 3 types of parts in DC high speed circuit breaker are considered. The open-close coil uses the principle of the electromagnet to maintain the main contact point of the circuit breaker. The auxiliary relay sends the status of breaker and disconnector to the control circuit. The limit switch is used to send the withdrawal status of breaker to the control circuit. The fault data refers to the fault history of the DC high speed circuit breaker which is currently being operated in subway substations. For the samples, circuit breakers are selected which have failed for the past seven years. Summary of failure history for the corresponding parts are listed in Table 1.

Table 1: Failure history of three parts in DC high speed circuit breaker

Parts	No. of failures	Average failure time (day)
Open-close coil	11	6,630
Aux relay	14	6,070
Limit switch	16	7,088

Table 2: Failure level in relation with C_u and C_p

Level	C_u/C_p	Remarks
High	>7	Equipment is not operated
Normal	5~6	Equipment is operated after repair
Low	1~4	Equipment is operated

Table 3: Optimal replacement period of three parts in DC high speed circuit breaker

Division	β	η	C_u/C_p	T_{OPT} (day)	Remarks
Open-close coil	6.478294	7081.5	2	5,457	β>1
Aux relay	1.478814	6949.5	6	4,086	β>1
Limit switch	1.463784	8285.2	8	3,873	β>1

The failure time is derived from the information on the date of the equipment installation and the failure occurrence. After applying the derived Weibull distribution, the optimal replacement cycle is determined by calculating the replacement cost versus the operating time with the procedure shown in Fig. 1. In case of β<1, the failure rate decreases, thus, it is excluded from the calculation of the optimal replacement cycle. The failure level of equipments depends on the value of C_u/C_p. This is important factor to decide the optimal replacement cycle. The classification of the value of C_u/C_p is shown in Table 2.

The results of the optimal replacement period analysis are shown in Fig. 2-4 and Table 3. Figure 2 shows that the graphs of the failure rate function and replacement costs vs. operating time of open-close coil. Since, the shape parameter β is larger than 1, the failure rate increases with time. The increase of failure rate can be caused by the deterioration of parts, thus, it is essential to take countermeasures before the severe failure occurs.

The graphs of failure rate functions and replacement costs vs. operating time of aux. relay and limit switch are shown in Fig. 3 and 4, respectively. The optimal replacement cycle for both parts can be also obtained following the same procedure used in case of the open-close coil.

It can be seen that the parts of DC circuit breaker could fail even before the end of their normal lifespan

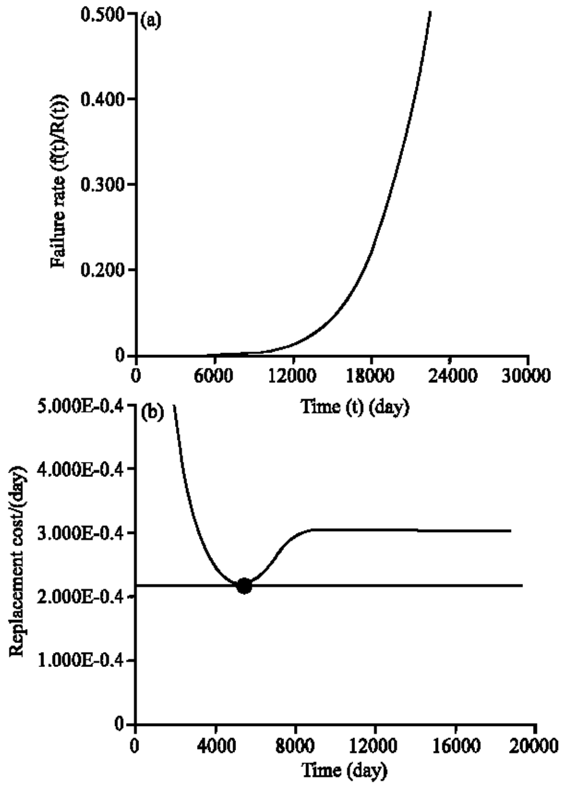

Fig. 2: Failure rate function and replacement cost vs. operating time (open-close coil)

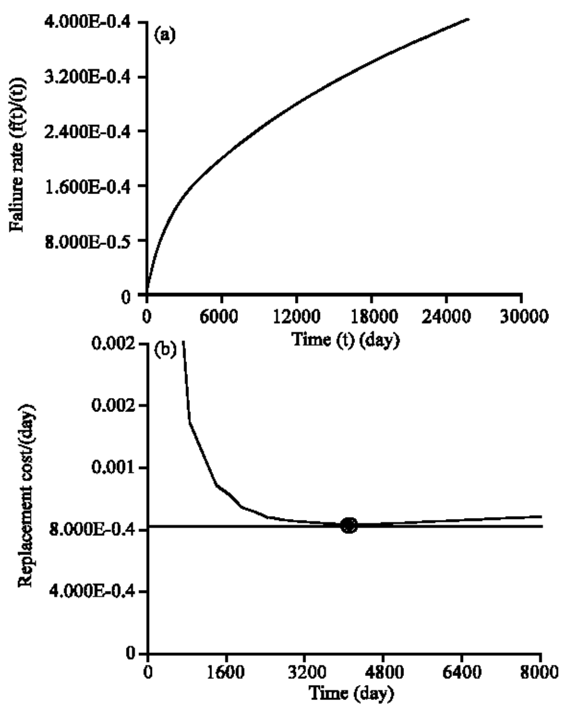

Fig. 3: Failure rate function and replacement cost vs. operating time (aux. relay)

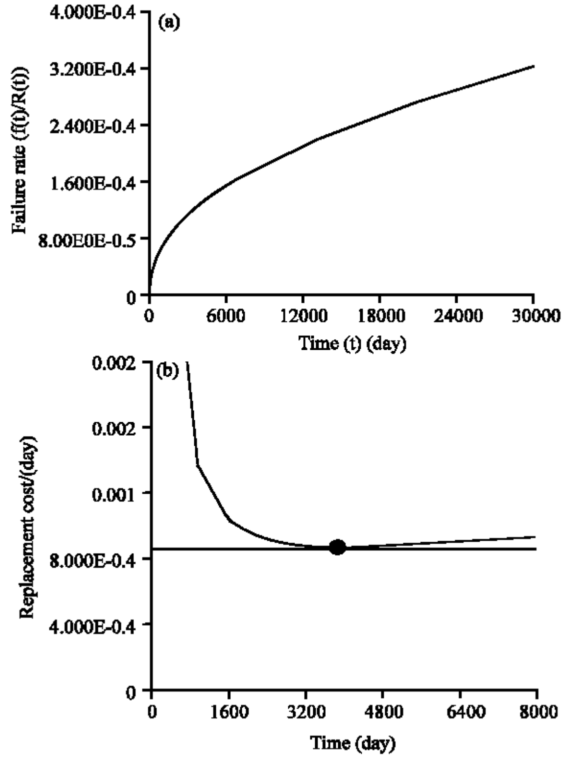

Fig. 4: Failure rate function and replacement cost vs. Operating time (limit switch)

(20 years) as shown in Fig. 2-4. The unexpected malfunctions of circuit breaker could lead to the secondary damage including the delay in train operation. The lifespan extension of equipments and the prevention of the secondary damage can be achieved by replacing the parts at the right time. Table 3 lists the estimated optimal period for each part and important parameters used in the estimation procedure.

CONCLUSION

The optimal replacement cycle is a function of the ratio of pre-maintenance cost and post-maintenance cost. If the post-maintenance cost including the recovery cost and the social cost from secondary damage is high, more frequent replacement is required resulting in the short period of replacement interval. Whereas if pre-maintenance cost is low, the corresponding equipment can keep operating through the regular examination rather than replacement of its parts for relatively longer period of time. In this study, the failure history of the three parts in the DC high speed circuit breaker is utilized to analyze their replacement cycle. Experimental results show that, the maintenance process can be improved from the economical and safely point of view in case the optimal replacement period of parts is applied in the field.

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