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STATISTICAL ANALYSIS OF MINIMUM OIL CIRCUIT BREAKER FAILURES

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Abstract

In this paper, remaining useful life (RUL) of circuit breakers (CB) has been analyzed, based on statistical data gathered during CB's maintenance. Using statistical data of 427 CBs gathered in past 10 years, Weibull probability distribution of contact resistance for breakers on both overhead and underground feeders and voltage levels of 35 kV and 10 kV is determined. With this methodology CB's condition can be observed by using real field data which are collected regullary during power station revision. [1]

Keywords and phrases: *circuit breaker, remaining useful life, voltage drop, Weibull distribution*

1 Introduction

Circuit breaker is a device used for switching feeder power supply in any working mode (normal load, no load, short circuit current...), and therefore represents the vital element of power system operation. CB failure threatens work of other equipment, which directly affects reliability of whole substation. This makes good reason of analyzing CB working behavior and its RUL.

To determine economic effects of maintenance, overhaul or CB removal [1], [2], assessment of circuit breakers remaining useful life (RUL) must be done [3], [4]. Remaining useful life is the lifetime from current time to the time that the device fails [1]. It is random variable which depends on various factors (device age, working conditions, and level of maintenance) [5]. If the failure time of the population follows the probability density function (PDF) f(t), then the population mean time to failure (MTTF) can be calculated by (1):

$$MTTF = \int_0^\infty tf(t)dt = \int_0^\infty R(t) \tag{1}$$

[1]PACS: 84.70.+p

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R(t) is the survival function at *t*. Let define X_t as the random variable of the RUL at time *t*, then the probability density function (PDF) of X_t conditional on Y_t is denoted as $f(x_t/\,Y_t)$ where Y_t is the history of operational information up to *t*. If $Y_t$is not available then the estimation of $f\ (x_{t/}\,Y_t)$ is:

$$f(x_t/Y_t) = f(x_t) = \frac{f(t+x_t)}{R(t)} \tag{2}$$

where $f(t+xt)$ is the PDF of the life at $t+x_t$

CB's reliability analysis depends of type of available data, which can be: contact resistance, commutation noise, erosion resistance, ultrasound detectors, transient earth voltage, infrared thermo scanning, CB control circuit data and collected data of CB faults. Depending of collected data type, RUL can be assessed with: knowledge-based models (fuzzy method); life expectancy models (statistical method [5] – [9]); artificial neural networks and physical models [4].

Utilities, grid operators and industrial power consumers are facing unprecedented challenges. With increasingly aging infrastructure combined with cost-cutting pressures to operate into today's competitive environment, prioritizing investment has never been so important.

Because of importance of reliability, some companies are started to use software, algorithms and analysis techniques for reliability management services to provide substation owners with the right insights to make optimal investments to improve system performance.

2 CB Ageing Process

The main causes of CB deterioration are the age, the number of operations under normal and fault conditions and the operational conditions like the temperature and contaminants content.

Measuring the contact resistance is usually done by using the principles of Ohm's law. Since the interrupting chamber is a closed container, we have only access to the entry and exit conductors; the measured R between these two points would be the sum of all the contact resistances found in series. According to the IEC 60694 [10], article 6.4.1, the current value to use should be the closest to the nominal current the interrupting chamber is designed for. If it is impossible to do so, lower currents can be used but not less than 50 A to eliminate the galvanic effect that might affect the readings.

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2.1 Data collecting

Analysis in this paper covers 42 35/10 kV substations of Serbian state owned utility "EPS Distribucija" and 427 circuit breakers, mounted on 10kV and 35kV feeders. Measurement of static contact resistance presented by the voltage drop on contacts is collected in past 10 year period (2007 – 2017), where voltage drop was measured every two years.

Other data regarding to circuit breakers that are collected are: voltage level, feeder type, manufacturing year, number of fault trips, number of short circuit current trips, number of customers, and annual consumption.

Depending on CB's nominal current and nominal voltage allowed voltage drop goes from 3.5 mV up to 14 mV [11]. Analyzed CBs have following maximal voltage drop values: 35 kV CB's: 3.5 – 7 mV; 10 kV CB's: 7 – 14 mV.

Manufacturer manual [11] states that CB must be completely overhauled after: 10-12 years of service, or 5000 operations, or 6 short-circuit currents breaking.

Measurement has been done with DC current of I = 100A, measuring voltage drop on every CB's pole. Figure 1 shows voltage drop distribution among all currently available data, with values divided into 4 categories depending of voltage drop level.

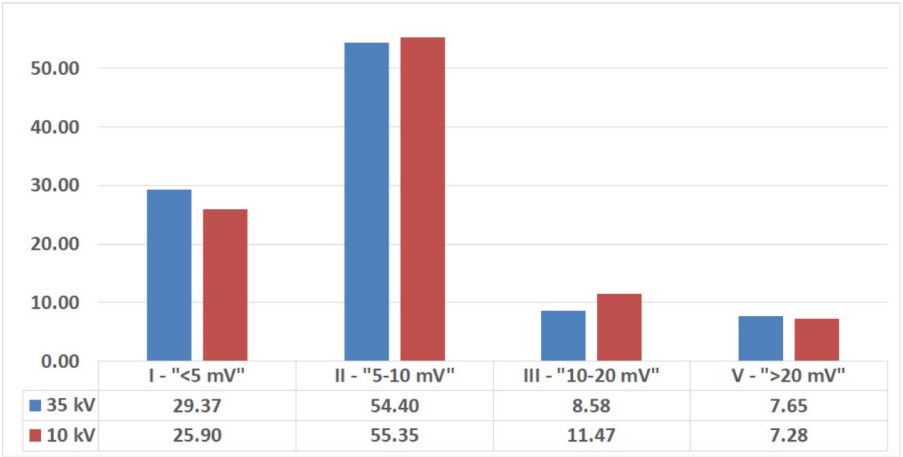


Figure 1: Voltage drop distribution on analyzed circuit breakers

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2.2 Data analyzing

In the first step, state of every CB is determined, according to its voltage drop value. CBs with voltage drop value beyond permissible are set in "failed" state (F), and those which still have voltage drop value below allowed are in "suspension" state (S). For failed CB's, the precise year of reaching that condition is defined. Such data are divided into following categories:

1. Circuit breakers on 35 kV feeders
2. Circuit breakers on 10 kV feeders
3. Circuit breakers on overhead feeders
4. Circuit breakers on underground feeders
5. All circuit breakers

From manufacturers manual [11] allowed voltage drop values are dependent on CB's rated voltage and rated current, and manufacturer allows them to surpass the permissible value for 25%. For that reason, CB's are also analyzed for two different criterions:

1. Maximal allowed voltage drop value is as in manufacturers table,
2. Maximal allowed voltage drop is 25% greater than recommended values.

That way, impact on CB's condition for both criterions is taken into account.

Obtained correlation coefficients in the curve fitting process are showing the great correlation to the Weibull probability distribution. The closer the value of Rho is to 1, the better the linear fit. Values of Rho are presented in Table I.

Correlation Coefficient [12] is a measure of how well the linear regression model (the probability line) fits the data. In the case of life data analysis, it is a measure of the strength of the linear relation (correlation) between the median ranks and the data. The population correlation coefficient is defined as follows:

$$\rho = \frac{\sigma_{xy}}{\sigma_x \sigma_y} \tag{3}$$

where σ_{xy} is the covariance of x (times-to-failure) and y (median ranks), σ_x is the standard deviation of x, and σ_y is the standard deviation of y.

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Table 1: Correlation coefficient values

Feeder type	**Correlation Coefficient Rho** (ρ)
overhead +25%	0.985203
overhead	0.992959
underground +25%	0.975994
underground	0.964724
10 kV +25%	0.988244
10 kV	0.989144
35 kV +25%	0.972266
35 kV	0.983755
all feeders +25%	0.988580
all feeders	0.990089

The estimator of ρ is the sample correlation coefficient, given by:

$$\widehat{\rho} = \frac{\sum_{i=1}^{N} x_i y_i - \frac{\sum_{i=1}^{N} x_i \sum_{i=1}^{N} y_i}{N}}{\sqrt{\left(\sum_{i=1}^{N} x_i^2 - \frac{\left(\sum_{i=1}^{N} x_i\right)^2}{N}\right)\left(\sum_{i=1}^{N} y_i^2 - \frac{\left(\sum_{i=1}^{N} y_i\right)^2}{N}\right)}} \tag{4}$$

Weibull distribution function (5) is two-parametric distribution, with slope parameter η and shape parameter β.

$$F(t) = 1 - e^{\left(\frac{t}{\eta}\right)^{\beta}} \tag{5}$$

Slope parameter shows time at which 63.2% of analyzed units are failed. Shape parameter represents failure rate behavior. Its value tells whether failures are decreasing or increasing. β<1 indicates infant mortality, while β>1 shows wear out failures. Higher value of beta indicates greater rate of failure. Both β and η parameters are calculated for the whole CB population from the statistical data using the least square method [13]. Results are presented in Table II.

Weibull distribution function with right censored data (case when some devices didn't fail during period of analysis) unreliability is calculated for all CB's categories. On figures 2-5 unreliability distribution of different criterions is shown.

By observing Weibull parameters two conclusions could made, underground feeders (both criteria of voltage drop value limit) have highest β while overhead

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Table 2: Weibull parameters

CB feeder type	η	β	**Fail \Suspend**
Overhead +25%	39.1	5.2	100 \87
Overhead	37.1	4.8	131 \56
Underground +25%	41.5	6.1	63 \169
Underground	38.1	6.1	97 \135
10 kV feeders +25%	43.4	5.6	87 \224
10 kV feeders	40.4	5.1	135 \176
35 kV feeders +25%	35.2	5.6	79 \31
35 kV feeders	33.8	5.6	96 \14

feeder have lowest value. Considering η parameter, 10 kV feeders (+25% limit voltage drop level) have closer time to failure, while 35kV feeders have lowest η value.

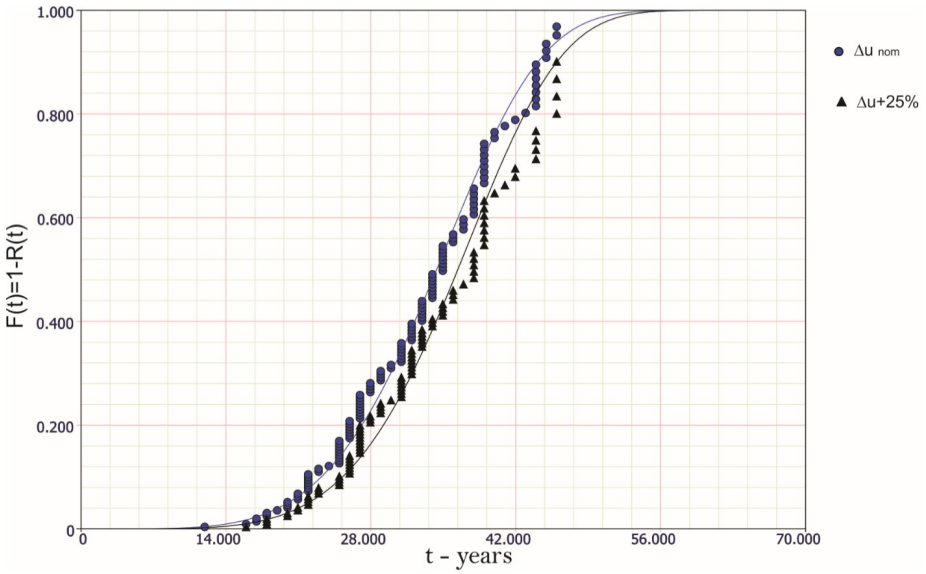


Figure 2: Weibull unreliability distribution for CB's on overhead feeders

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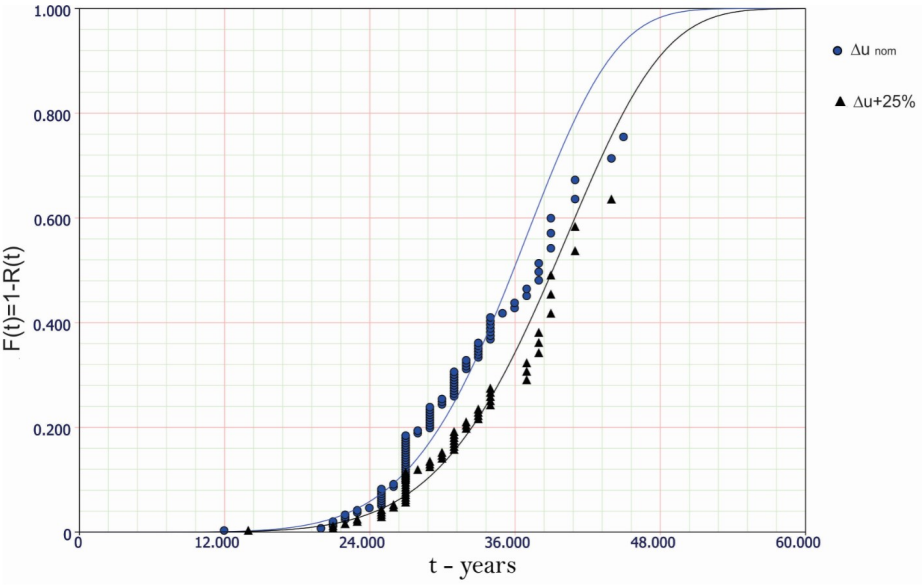


Figure 3: Weibull unreliability distribution for CB's on underground feeders

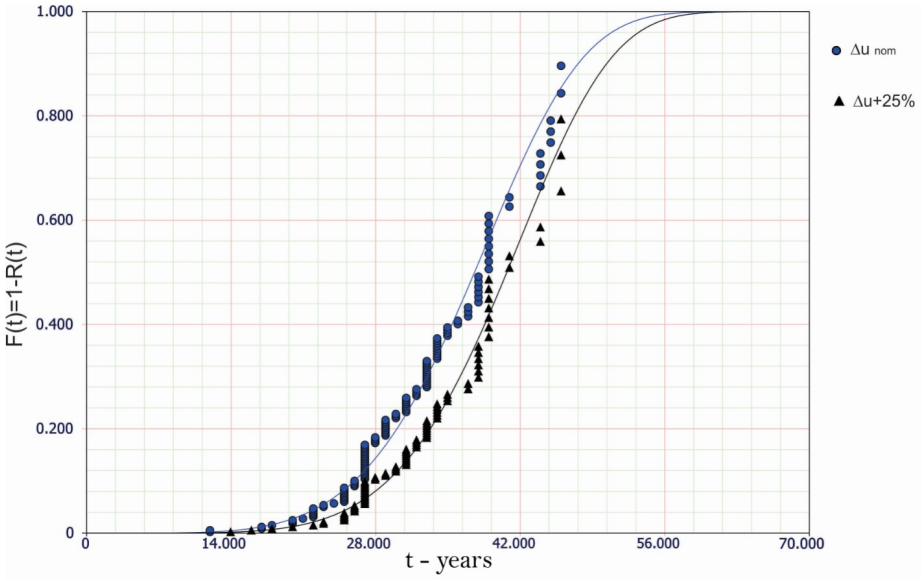


Figure 4: Weibull unreliability distribution for CB's on 10 kV overhead feeders

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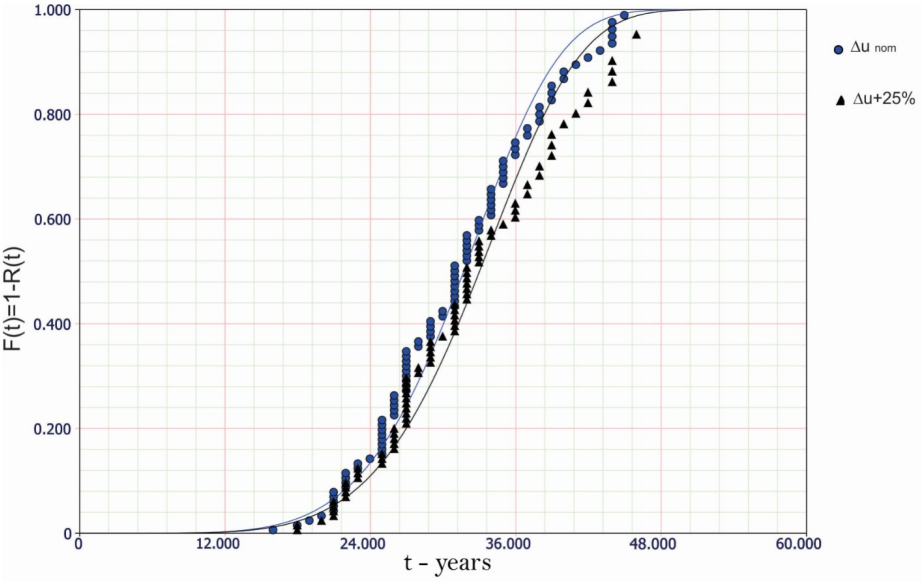


Figure 5: Weibull unreliability distribution for CB's on 35 kV overhead feeders

3 Conclusion

The determination of CB remaining useful life is a complex procedure depending on various stochastic factors, including the current flowing through the CB, breaking current intensities, number of operations and operational conditions as well. In this methodology, RUL is determined implicitly, by the assessment of risk of failure from keeping the CB in operation, with the diversification of normal and abnormal operation conditions.

The total of 427 circuit breakers has been monitored, with data gathered in past 10 years. After the statistical tests, parameters for Weibull probability distribution of contact resistance for breakers on both overhead and underground feeders were determined. Weibull probability distribution of contact resistance for breakers on both overhead and underground feeders and voltage levels of 35 kV and 10 kV proved to be the best fit.

The proposed methodology requires historical data of different control parameter measurement and proved to be useful when the changes of breaker operational conditions are expected. The statistical analysis showed that the dominant feeder type (overhead or underground) has a great influence on probability of failure, and that these conditions must be taken into account in a quantitative way.

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