Failure Rate Analysis of Power Circuit Breaker in High Voltage Substation

Thanapong Suwanasri, May Thandar Hlaing and Cattareeya Suwanasri

Abstract— *This paper proposes the failure rates of power circuit breakers at the system voltage level of 115kV for control and protective system in power substation. Firstly, the recorded failure data of the existing power circuit breakers in the high voltage substations are analyzed. Secondly, the data analyzes are performed such as the classification of different failure types by separating three main groups such as live parts and insulation, control parts, and operating mechanism parts during the failure event year period from 1989 to 2011 including the total number of failed 607 power circuit breakers. Finally, failure rates and mean time between failures (MTBF) for all components in each main part can be estimated by using Weibull distribution technique is discussed for improving the reliability of the high voltage substations such as correct maintenance schedule or renovation tasks of equipment. The proposed method can also used with other high voltage equipment in the power system.*

Keywords— Age, failed types, failure rate, failure statistic, power circuit breaker.

1. INTRODUCTION

Power circuit breaker is one of the most important protection and control apparatus in the power system. It's functions are used to sense a fault current for the control relay to operate the trip opening mechanism and then interrupt the electric circuit for preventing the power supply interruption in the power system. The power circuit breakers with high failure statistic should be analyzed intensively for preventing unpredictable failure in order to determine the reliability of circuit breakers components and system reliability. Various numbers and technologies of power circuit breakers were installed in the power system. The deterioration of power circuit breakers depends on equipment quality, operation such as load stress, maintenance, surrounding environment such as temperature, moisture, pollution, and etc.

In this paper, power circuit breakers at the system voltage level of 115kV including the total number of failed 607 breakers during the period from 1989 to 2011 have been analyzed. The objective of this paper is to describe a method for estimating the key reliability parameters such as failure rate and mean time between failure (MTBF) from recorded failure data of the Electricity Generating Authority of Thailand (EGAT) by using Weibull distribution technique for improving the reliability evaluation purpose. Then, the correct maintenance schedule or renovation tasks of equipment with the minimum cost can be applied.

2. CLASSIFICATION OF FAILURE TYPES FOR RELIABILITY ANALYSIS

As the normal opening and closing motion of the power circuit breakers depends on their components working capability, control, and operating mechanisms are very important for the performance and reliability of power circuit breakers [1]. In this paper, the components of circuit breaker are divided into three main parts such as live parts and insulation, control parts, and operating mechanism parts. Firstly, the live parts and insulation are separated into two sub-components that consist of (1)main insulation to earth and (2)making and breaking units. Secondly, control parts include (1)auxiliary switches and associated drives, (2)contractors, relays, heaters, thermostats, fuses, (3)gas density supervision, and (4)triping and closing units. Lastly, operating mechanism parts take account of (1)actuator, (2)compressors, motors, pump, pipe union, (3)control elements, (4)counter, (5)damping device, (6)energy storage, (7)mechanical transmission, and (8)no return device, respectively.

The numbers of failed breakers for each main part are 91units, 153units, and 363units respectively and totally 607 breakers are observed. According to the recorded failed data, the most failure percentages are 52% at making and breaking units for live parts and insulation, 30% at contractors, relays, heaters, thermostats, fuses for control parts, and 23% at counter for operating mechanism parts. The second are the main insulation to earth 48%, gas density supervision 27% and mechanical transmission 14% for each main part respectively as shown in the Figure-1 to Figure-3.

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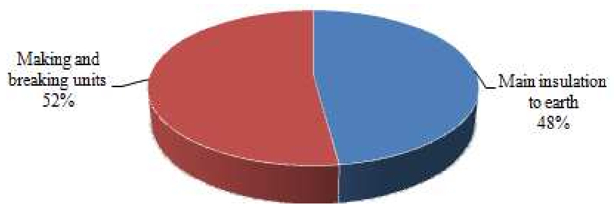

Fig.1. Failure Percentage for Live Parts and Insulation

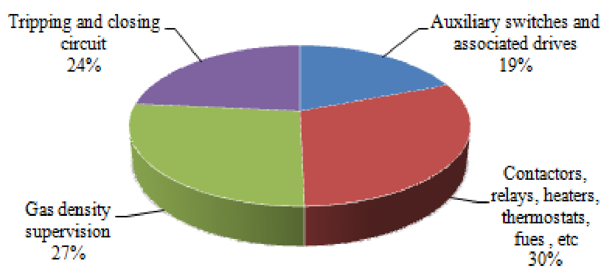

Fig.2. Failure Percentage for Control Parts

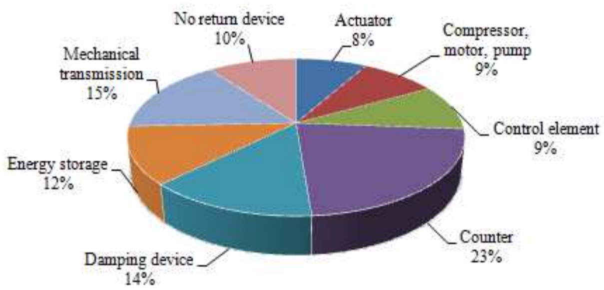

Fig.3. Failure Percentage for Operating Mechanism Parts

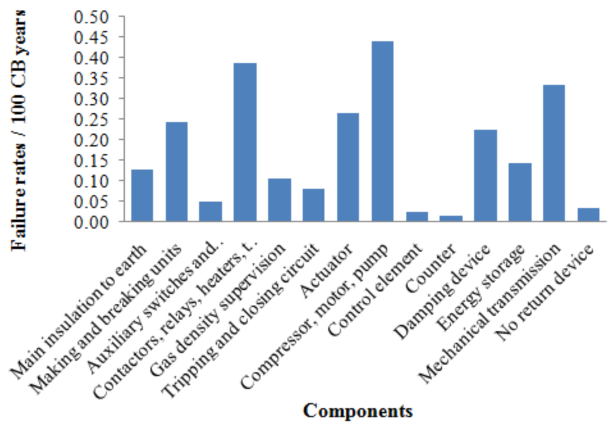

Fig.4. Failure Rates for All Components of Circuit Breaker

Table 1 represents the number of failures by 100CB years for all components in each main part [2]. Their results are shown in Figure-4. It can be seen that the most failures rate is 0.441 at compressor, motors, pumps, pipe union of operating mechanism part. The second is 0.388 at contractors, relays, heaters, thermostats, fuses of the controls parts, and the third failure rate is 0.335 at mechanical transmission of operating mechanism parts respectively.

Table 1. All Components and Their Number of Failures

Type of Components	No. of failures	CB years	No of failures/ 100CB years
Main insulation to earth	31	24472	0.127
Making and breaking units	60	24472	0.245
Auxiliary switches and associate drives	12	24472	0.049
Contractors, relays, heaters, etc	95	24472	0.388
Gas density supervision	26	24472	0.106
Tripping and closing circuits	20	24472	0.082
Actuator	65	24472	0.266
Compressors, motors, pumps, pipe union	108	24472	0.441
Control elements	6	24472	0.025
Counter	4	24472	0.016
Damping device	55	24472	0.225
Energy storage	35	24472	0.143
Mechanical transmissions	82	24472	0.335
No return device	8	24472	0.033
Total	607		

3. METHOD FOR ESTIMATING RELIABILITY PARAMETERS

Weibull distribution technique is one of the most widely used for accurate failure analysis, failure forecast, aging and reliability [3]. Firstly, the recorded failure data of the existing power circuit breakers in the high voltage substations are analyzed. Then an order of failure events is ranked. Finally, median rank F(t) or probability of failure is calculated by Equation (1).

$$\text{Median Rank} = \frac{i-0.3}{N+0.4} \qquad (1)$$

where "i" is the adjusted rank and "N" is the number of failures observed.

Weibull parameters can be determined by using straight line formula as follows.

$$y = mx + c \qquad (2)$$

where, $$y = \ln \ln \left[\frac{1}{1-F(t)} \right] \qquad (3)$$

$$m = \beta = \frac{\sum_{i=1}^{N} x_i y_i - \frac{\sum_{i=1}^{N} x_i \sum_{i=1}^{N} y_i}{N}}{\sum_{i=1}^{N} x_i^2 - \frac{\left[\sum_{i=1}^{N} x_i \right]^2}{N}} \qquad (4)$$

$$x = \ln(t) \tag{5}$$

$$c = \frac{\sum_{i=1}^{N} y_i}{N} - m\frac{\sum_{i=1}^{N} x_i}{N} \tag{6}$$

$$\eta = e^{-\left[\frac{c}{m}\right]} \tag{7}$$

The Weibull probability distribution function (PDF) represents the probability of failure at specific time (t), as written by Equation (8).

$$f(t) = \left(\frac{\beta}{\eta}\right)\left(\frac{t}{\eta}\right)^{\beta-1} e^{-\left[\frac{t}{\eta}\right]^{\beta}} \tag{8}$$

The Weibull cumulative distribution function (CDF) represents the probability of failure at specific time (t), as written by Equation (9) while the reliability and failure rate by Equations (10)-(11).

$$F(t) = 1 - e^{-\left(\frac{t}{\eta}\right)^{\beta}} \tag{9}$$

$$R(t) = 1 - F(t) = e^{-\left(\frac{t}{\eta}\right)^{\beta}} \tag{10}$$

$$\lambda(t) = \frac{f(t)}{R(t)} = \left(\frac{\beta}{\eta}\right)\left(\frac{t}{\eta}\right)^{\beta-1} \tag{11}$$

where β is the shape parameter and η is the life or scale parameter.

Mean time between failures (MTBF) is calculated by using Equation (12).

$$MTBF = \eta\,\Gamma\left[1 + \frac{1}{\beta}\right] \tag{12}$$

where, $\Gamma\left[1+\frac{1}{\beta}\right]$ is the gamma function evaluated at the value of $(1+ 1/\beta)$.

The Weibull cumulative distribution function F(t) for three main parts are as shown in Figure-5 to Figure-7[3]. The horizontal axis shows the values of (x) and the vertical axis is the values of (y) by using Equations (5) and Equation (3) [4].

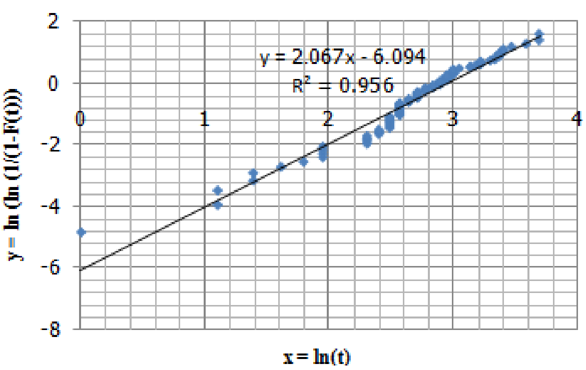

Fig.5. Straight Line of F(t) for Live Parts and Insulation

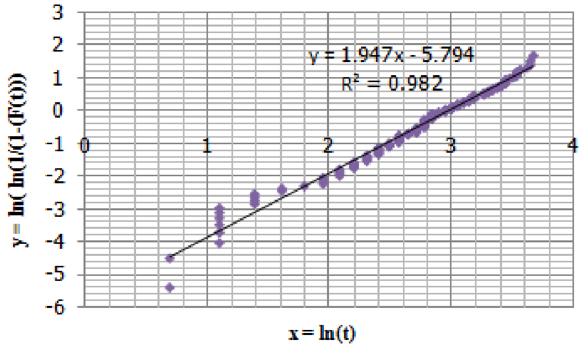

Fig.6. Straight Line of F(t) for Control Parts

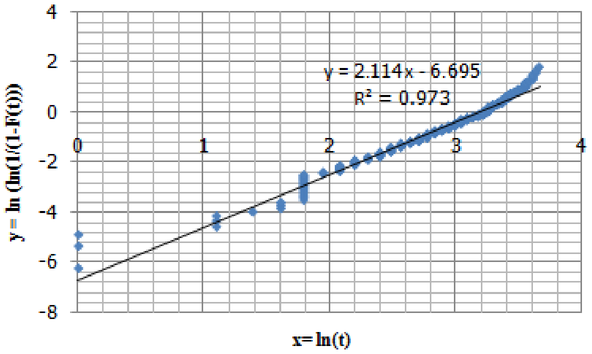

Fig.7. Straight Line of F(t) for Operating Mechanism Parts

4. STATICAL FAILURE ANALYSIS OF POWER CIRCUIT BREAKER

Calculating procedure of Weibull analysis involves data acquisition, data ranking, data plotting and outcome interpreting. After ranking by using Equation (1), the number of failure events are known [3]. Table-1 shows the Weibull reliability parameters, MTBF, and failure rate (λ) of power circuit breakers at the level of voltage 115kV are summarized from historical record from 1989 to 2011 which are scattering and paper-based in nature, are systematically recorded in the central database. Benefits of Weibull analysis are that it provides rationally accurate failure analysis [3]-[6].

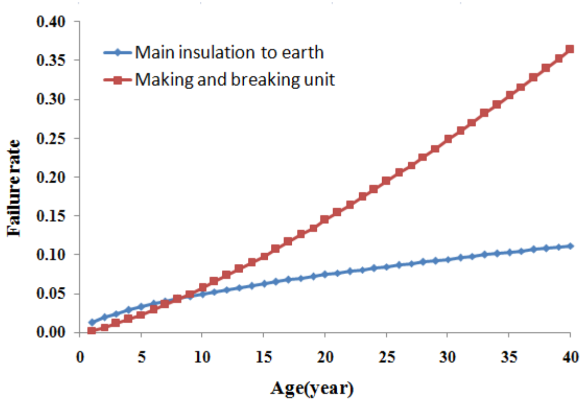

Fig.8. Failure Rates for Live Parts and Insulation

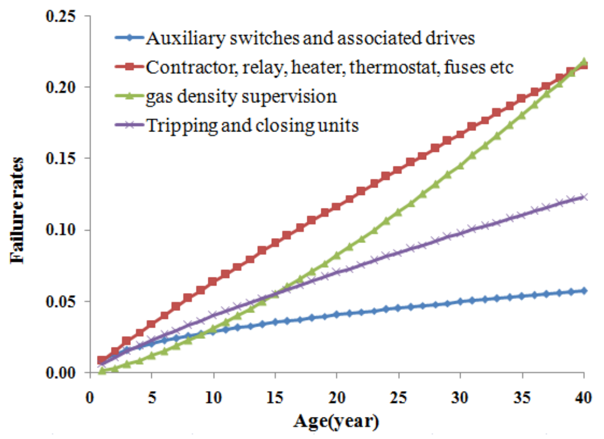

Fig.9. Failure Rates for Control Parts

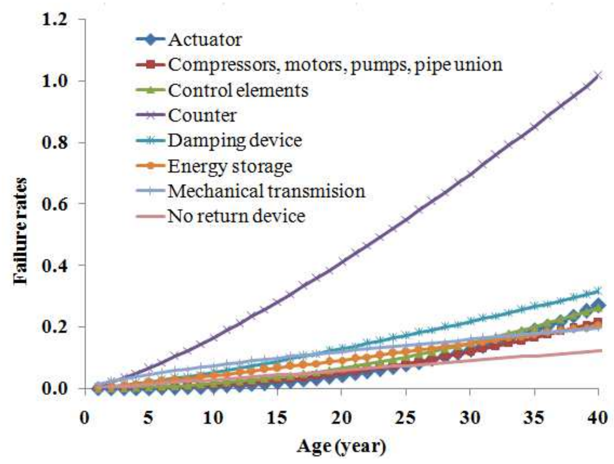

Fig.10. Failure Rates for Operating Mechanism Parts

The most failure rate occurs at making and breaking unit for live parts and insulation as shown in Figure-8. For the control parts, contractors, relays, heater, thermostats, fuses is the most failure occurred and the second failure rate is at gas density supervision as shown in Figure-9. According to Figure-10, the most failure rate is at counter and the second is at damping device for operating mechanism parts.

Table-2 represents the reliability parameters, MTBFs and failure rates for each component. It can be seen that the most failure rates are 0.1664(freq/year) at counter, 0.107(freq/year) at making and breaking units, and 0.1052(freq/year) at damping devices .The second failure rates are 0.0957(freq/year) at contractors, relays, heaters, thermostats, fuses etc. and 0.0946(freq/year) at mechanical transmission. The least failure rates are 0.0469(freq/year) at auxiliary switches and associated drives respectively [3].

Figure-11 shows the failure rates and the MTBF for each part of the circuit breaker. The most failure rate is at live parts and insulation, the second is at control parts and the least failure rate is at operating mechanism parts.

Table-3 shows the reliability parameters, MTBFs, and failure rates for each main parts. It can be seen that the life time of breaker (MTBFs) are nearly the same amount of 17(year) at liveparts and insulation and control parts. For operating mechanism parts is 21(year). The most failure rate is 0.0960 (freq/year) at live parts and insulation. The second is 0.0869 (freq/year) at control parts and the last failure rate is 0.0777 (freq/year) at operating mechanism parts.

Table 2. Reliability Parameters, MTBF, and Failure Rate for Each Component

Type of Components	Weibull Parameters		MTBF (year)	Failure Rate (λ) (freq/yr)
	β	η		
Main insulation to earth	1.5895	20.8894	18.8005	0.0697
Making and breaking units	2.3355	18.2773	16.4496	0.1070
Auxiliary switches and associated drives	1.4972	30.1995	27.1795	0.0469
Contractors, relays, heaters, thermostats, fuses	1.8873	17.8765	16.0889	0.0957
Gas density supervision	2.4086	23.4442	21.0998	0.0880
Tripping and closing circuits	1.8178	23.1004	20.7904	0.0699
Actuator	3.6509	29.7327	26.7594	0.0860
Compressors, motors, pumps, pipe union	3.1011	28.5908	25.7317	0.0818
Control elements	2.9999	26.3143	23.6829	0.0871
Counter	2.3048	11.5177	10.3660	0.1664
Damping device	2.2862	18.9271	17.0344	0.1052
Energy storage	2.1336	21.3189	19.1870	0.0878
Mechanical transmission	1.6907	16.1716	14.5544	0.0946
Non-return device	2.0399	25.9740	23.3766	0.0692

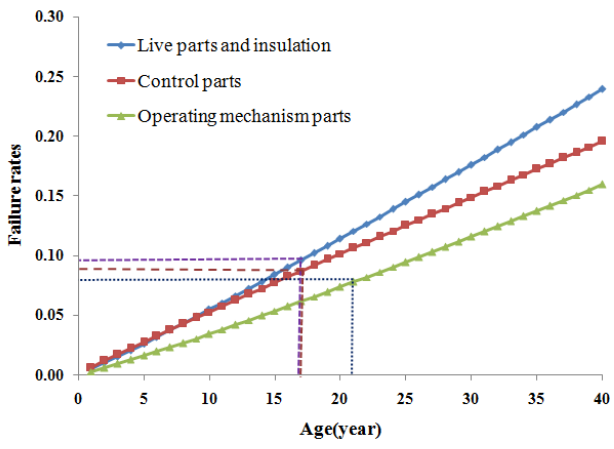

Fig.11. Failure Rates and MTBFs for Each Main Part

Table 3. Reliability Parameters, MTBF, and Failure Rate for Each Main Part

Type of Components	Weibull Parameters		MTBF (year)	Failure Rate (λ) (freq/yr)
	β	η		
Live parts and insulation	2.0676	19.0644	17.1580	0.0960
Control parts	1.9474	19.5946	17.6351	0.0869
Operating mechanism parts	2.1140	23.7381	21.3643	0.0777

4. COMPARISON OF FAILURE RATES FOR ALL COMPONENT

Figure-12 shows the Weibull cumulative distribution function F(t) for all components[3]. Similarly, Fig.13 shows the failure rate and MTBF of all components in the breaker at associated voltage level. In addition, Table-4 shows the values of Weibull parameters, MTBF, and the failure rate of combined all components in the circuit breaker at 115kV voltage level. Each value are 2.0695, 21.8984, 19.7096, and 0.0812 respetively.

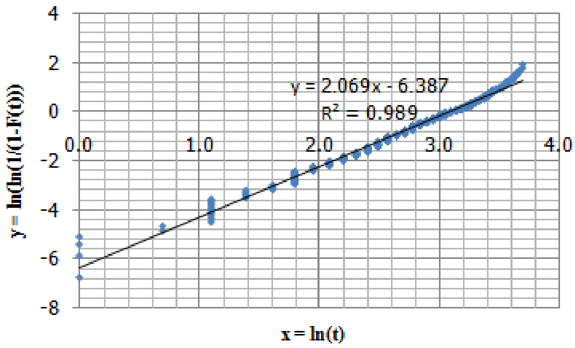

Fig.12. Straight Line of F(t) for Combined All Components

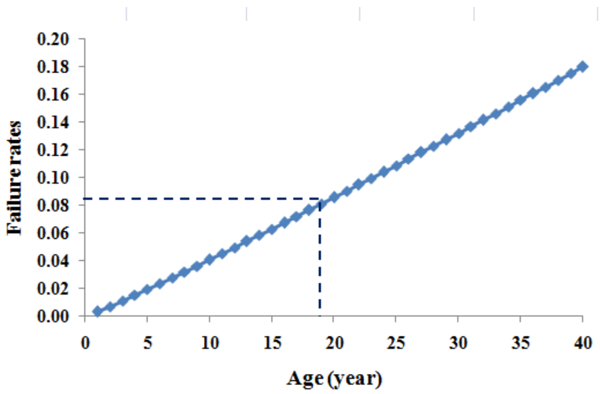

Fig.13. Failure Rate and MTBF for All Components

Table 4. Reliability Parameters, MTBF, and Failure Rate for All Components

Type of Components	Weibull Parameters		MTBF (year)	Failure Rate (λ) (freq/yr)
	β	η		
All components	2.0695	21.8984	19.7086	0.0812

5. CONCLUSIONS

In this paper, the total number of failed 607 breakers are considered during the event year 1989 to 2011 which are originated from separating three main parts such as live parts and insulation, control parts, and operating mechanism parts at the system voltage 115kV. After that, all components failure data are combined and compared the results.The life times of breakers and the failure rates can be calculated from the recorded failure data of EGAT by using Weibull statistic distribution technique.

The value of shape parameter (β) can describe the failure mode of the devices, power circuit breakers in this paper. According to the results, the values of (β) for three main parts are greater than 1. It means that the failure rates are very low at the beginning and significantly higher with increasing time. This can be seen that the failure rates of the components depend on the aging. The life or scale parameter (η) represents the time for which the failure percentage is 63.2%. The MTBF represents the life time of device, in this paper power circuit breaker. The MTBFs are nearly the same amount of 17 year at live parts and insulation and control parts, 21 year at operating mechanism parts and all components is 19 year respectively. The failure rates are nearly the same amount of 0.09 for live parts and insulation and control parts, 0.08 for operating mechanism parts and all components.

Each component has its own failure rate, but the performance of circuit breaker as a whole part depends on the state of all components. For reliability point of view, the breaker components are connected in series, so failure of a single component prevents proper fault interruption and causes breaker failure. If reliability of the components decreases, the system reliability can also be decreased. So, the correct maintenance schedule or renovation tasks of equipment are required for reliability evaluation.

According to the results, the proposed method is approximated life time of the equipment for strategy planning on reliability evaluation. Finally, the study results can be carried out and estimated failure rate, and the life time (MTBF) of other high voltage equipment in the power system.

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