The Analysis of Failed-type and Symptom of High Voltage Circuit Breaker for Performance Assessment

Thanapong Suwanasri, Sakda Nobnorp, Sarawut Wattanawongpitak, and Cattareeya Suwanasri

Abstract— *The performance of high voltage equipment in electrical power system should be assessed and clearly identified as supported reasons for planning the renovation task of electrical asset. Thus, the performance assessment based on failed-type and symptom for high voltage circuit breakers rated as of 115 kV, 230 kV and 500 kV are focused in this work. The scattering failure events are systematically recorded and analyzed by using statistical techniques. Since numbers of circuit breakers from each manufacturer are different, the failure rates of every manufacturer are calculated and compared. After that the failure evaluation is performed. Then, the symptoms of failure are classified for each voltage level. The known failure rate and symptom are used as criteria for performance evaluation of those high voltage circuit breakers. The proposed criteria can also used with other high voltage equipment in the power system.*

Keywords— **Performance assessment, power circuit breaker, failed-type, symptoms, failure rates.**

1. INTRODUCTION

The major equipments in high voltage substation are power transformer, power circuit breaker, disconnecting switch, and instruments transformer. One of the most importance equipment is power circuit breaker. The power circuit breaker has its functions for switching or disconnecting the operating circuit for maintenance purpose as well as interrupting the fault current for preventing the blackout in power system. The power circuit breakers with high failure statistic should be analyzed intensively for preventing unpredictable failure and evaluating optimal operation and maintenance in order to determine maintenance schedule and save the maintenance costs of utility. 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. All aforementioned problems are the main effects to the equipment performance. They also cause the growing of the deterioration process. If the maintenance activity has not been approached properly, the equipment may encounter minor failures and extend to major failures in the future. Therefore, the major and minor failures of the specified part of equipment and specified manufacturer should be determined to prevent the huge disaster and help for maintenance decision making.

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This paper, presents the failure analysis of power circuit breakers in different voltage levels by classifying the minor and major failures in term of symptoms, and failed-type. The results show explicitly the causes of major or minor failures, and shown implicitly incorrect operation or inadequate maintenance. Then, the correct maintenance schedule or renovation of equipment with the minimum cost can be applied. In addition, the utility can differentiate the best manufacturer of the specified equipment.

2. FAILURE STATISTICS

Failure statistics is the number of event and data recorded in any utility in a given time over the long period. The failure data of power circuit breakers in high voltage substations of a utility in Thailand were recorded from year 1989 to 2011. However, the data has not been statistically recorded and analyzed. Consequently, the manufacturers, models, or parts that produce high failure rates cannot be predictable. From this reason, the failure statistic analysis should be achieved for indicating the performance of power circuit breakers according to visible deterioration such as symptoms, failed-types, and obsolescence as well as invisible deterioration such as aging and in-service stress. In this paper, only the first two mentioned criteria of the visible deterioration are focused. The historical failures are divided into two types: major and minor failures.

The major failures are the events occurred during circuit breakers operated and affected on surrounding equipment and caused power system outages. The minor failures were found during maintenance activities or visual inspection from operators [2]. Therefore, the symptom and failed-types can be analyzed in term of major failure and minor failure, respectively. The failure rate can be calculated as in Eq. (1).

$$\text{Failure Rate } [freq./year] = \frac{\text{Number of failure}}{\text{Total usage time}} \quad (1)$$

The failure rate represents the symptoms frequency per year of equipment of any manufacturer. Because of the power circuit breakers of any manufactures are not identical; the failure rate of each manufacturer should be calculated with the same basis as per 100 CB. Therefore, the Eq. (1) is modified as in Eq. (2).

$$Failure\ Rate\ [\,freq./100\ CB\ year] \;=\; Failure\ Rate\ \times 100 \qquad (2)$$

The failure rate can help the utility for choosing the better manufacturers with the better quality and performance.

3. FAILURE ANALYSIS AND RESULTS

The two aforementioned criteria, as symptom and failed-type, are statistically considered by classifying into the major and minor symptom of failures.

3.1 Failed-types Analysis

3.1.1. Failure Events

The failure events occurred of different manufacturers at different voltage levels were analyzed as follows.

In Table 1, the numbers of failures of a total 1,718 power circuit breakers at 115 kV level from 19 manufacturers are represented in form of manufacturers A to S. The total major and minor failure events occurred 344 and 542 times, respectively. The manufacturer A obtains the highest numbers of major and minor failures, which are 124 and 224 failures of the total 473 circuit breakers installed in the system. Although, the manufacturer A encounters the highest failure rate but it cannot be concluded that its devices has a poor performance. Because of the total number of installed devices is the highest. Similarly, the other manufacturers as F, G, K, L, M and N provide the failure rate significantly lower than manufacturer A. But it is unable to conclude that these manufacturers get better performance than manufacturer A, because of the number of installed devices are less than manufacturer A. In addition, they were probably not installed in the utility's high voltage substations for long periods [1].

Similarly, Table 2 and Table 3 present the number of failures from 15 manufacturers of the circuit breakers at 230 kV and from 8 manufacturers at 500 kV. In Table 2, by considering reliability perspective, the manufacturer B shows its worst performance. Because only 8 devices were installed at 230 kV high voltage substation but major failures occurred up to 40 times. However, these devices have been disconnected and replaced by the manufacturer E, which produces the better performance.

In Table 3, at 500 kV high voltage substations connected to power plant, almost of the power circuit breakers were not installed in transmission system. Majority, these power circuit breakers were not operated under high loading situation and not switched frequently. Then, it should obtain fewer failures; however, some manufacturers still obtain high failure rates such as manufacturer U with 9 major and 31 minor failures of the total 12 circuit breakers installed in substation.

Table 1. Number of Failures of Circuit Breakers in 115 kV High Voltage Substations

Manufacturers	Number of devices	Number of failures	
		Major failures	Minor failures
A	473	124	224
B	174	32	48
C	19	0	3
D	19	0	1
E	80	6	4
F	7	7	0
G	1	0	1
H	32	13	25
I	195	17	18
J	11	0	3
K	13	12	0
L	4	2	1
M	1	0	1
N	5	3	11
O	180	60	108
P	36	14	28
Q	64	2	5
R	197	14	26
S	207	38	35
Grand Total	1718	344	542

Table 2. Number of Failures of Circuit Breakers in 230 kV High Voltage Substations

Manufacturers	Number of devices	Number of failures	
		Major failures	Minor failures
A	289	62	84
B	8	40	24
D	5	0	1
E	8	0	0
F	3	1	0
H	2	2	1
I	141	13	14
L	12	18	20
N	92	25	105
O	22	19	24
P	44	19	55
Q	244	37	64
R	163	16	46
S	33	8	8
T	1	2	2
Grand Total	1059	262	448

Table 3. Number of Failures of Circuit Breakers in 500 kV High Voltage Substations

Manufacturers	Number of devices	Number of failures	
		Major failures	Minor failures
A	40	12	16
D	2	0	1
J	14	0	0
N	8	0	1
O	6	0	3
Q	36	2	2
U	12	9	31
W	6	1	10
Grand Total	124	23	64

3.1.2. Failure Rate Calculation

From failure records, the failure rates of different circuit breakers from different manufacturers can be calculated in form of frequency per 100 CB-year of failure rate [3].

Fig. 1 presents failure rates of 115 kV circuit breakers. Significantly, the minor failures occurred with manufacturers A, G, M, N and Q. For example, manufacturer Q encounters failure rate as of 4.2414 frequencies per 100 CB-year, which is the highest rate in this voltage level. The manufacturer G and M produced the failure rate as of 2.6316 and 3.4483 frequencies per 100 CB-year but the major failures have never occurred with them. The major failure rate of manufacturer L is 2.9412 that is the highest major failure rate of 115 kV substations; there is also minor failure occurred. Likewise the manufacturers F and K encounter 2.0772 and 2.8037 of major failure rates while there is no minor failure for both.

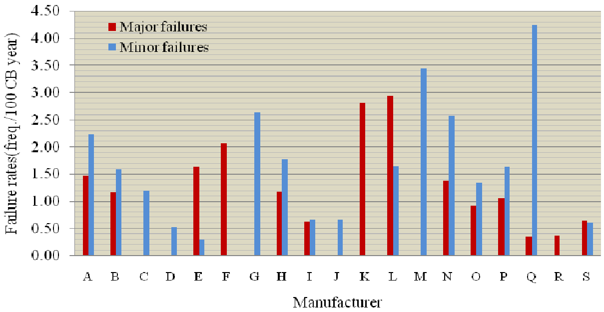

Fig.1. Failure Rates for 115 kV Circuit Breakers

Fig. 2 shows failure rates of 230 kV circuit breakers. The manufacturer B provides the highest major failure as 4.7114 times per 100 CB-year. These devices were uninstalled from the substation. The manufacturer L obtains 4.1096 major and 4.5558 minor failure rates from a total of 18 devices, which is considered as a high failure rates. The manufacturer T also obtains high failure rate because there is only 1 device was installed. Another manufacturer H encounters high major failures rate as 3.4483.

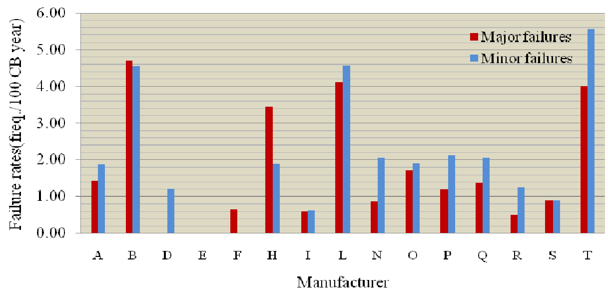

Fig.2. Failure Rates for 230 kV Circuit Breakers

Fig. 3 shows the 500 kV circuit breakers with only 8 manufacturers. The manufacturer W comes up with 1.5625 and 8.3333 for major and minor failure rates. The manufacturer U gets 2.0501 and 3.3991 for major and minor failure rates whereas the manufacturer A gets 1.6807 and 2.0513 for major and minor failure rate. There is no major failure for manufacturer D and O but there is minor failure rate. Comparing such failure rates with obtained from other manufacturers, there equipment are in lower quality.

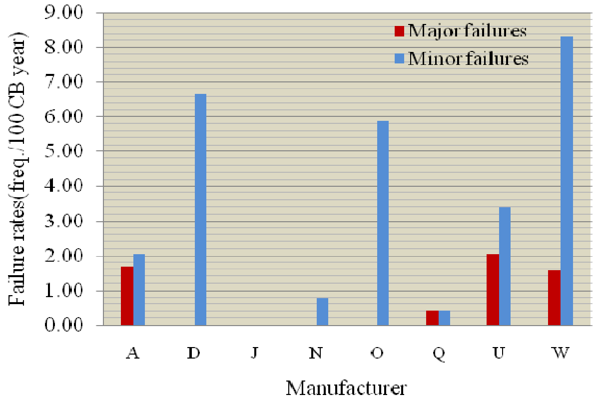

Fig.3. Failure Rates for 500 kV Circuit Breaker

Summarily, from the failure rates of power circuit breakers in three voltage levels interestingly, the manufacturer A is the most popular for each voltage level with its low failure rates. In the same way, the manufacturer R is largely installed in 115 kV and 230 kV systems with the low failure rates. That means the failure rate can be acceptable. Failure rates show the quality and performance of each manufacturer. However, it also depends on the operation and maintenance.

3.2 Symptom Analysis

The failure statistics are classified into major and minor symptoms [4].

3.2.1. Major Symptoms

Due to the severe effect when the failure occurred, the major symptoms must be considered into 13 categories as (1) Does not closed on command, (2) Does not opens on command, (3) Alarm & lockout in open or closed, (4) High contact resistance, (5) Opens without command, (6) Breakdown across open pole (internal), (7) Breakdown to earth, (8) Insulation lower than standard, (9) Operation timing does not standard, (10) Does not break the current, (11) Does not carry the current, (12) Does not make the current, and (13) Other. Fig. 4 to Fig. 6 show the major symptoms of power circuit breakers. The most frequent symptom is "Does not closed on command". Whereas the most cause of symptom are incorrect operation and maintenance, inadequate instruction for erection, stresses beyond those specified, bad contact in auxiliary control circuit and another cause that unknown [4].

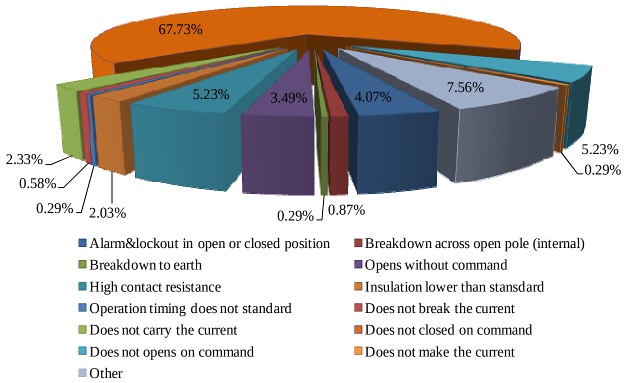

Fig.4. Major Symptoms of 115 kV Circuit Breakers

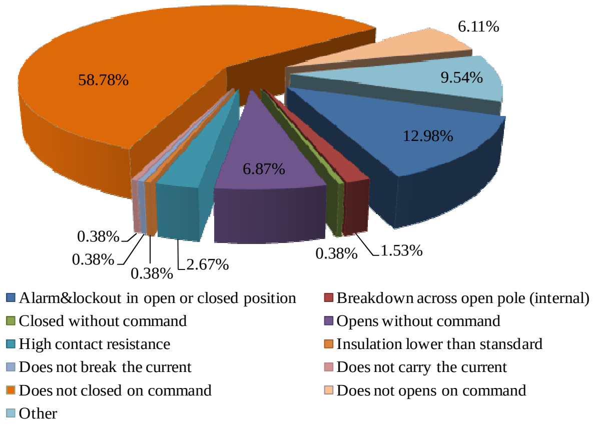

Fig.5. Major Symptoms of 230 kV Circuit Breakers

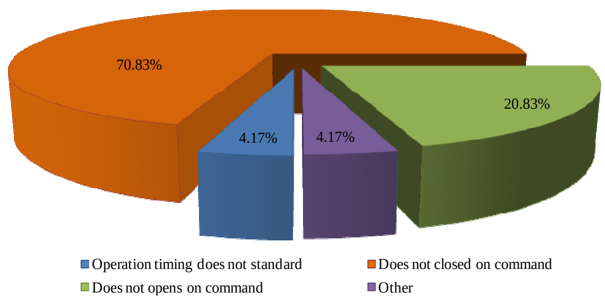

Fig.6. Major Symptoms of 500 kV Circuit Breakers

3.2.2. Minor Symptoms

The minor symptoms are classified into 5 categories as (1) Air or hydraulic oil leakage in the operating mechanism, (2) Change in functional characteristics, (3) Small SF6 leakage due to nut is not tight, (4) Small SF6 leakage due to corrosion and (5) Other. The most minor symptom in 115 kV voltage levels is "Air or hydraulic oil leakage in the operating mechanism". In a part of the other symptoms, the mostly symptoms may be not severe or severe such as breaker intermediate, does not charge spring, bad contact limit switch, counter failed and explosion event, etc [4].

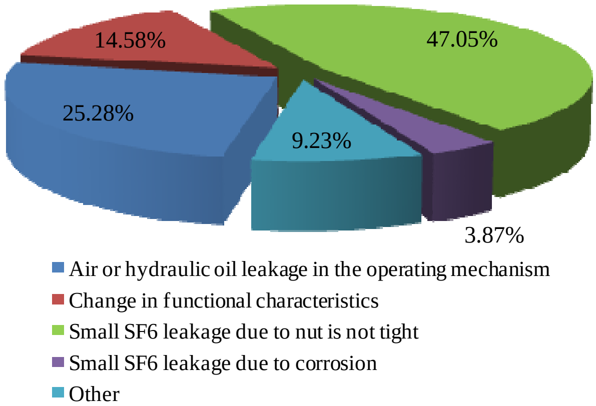

Fig.7. Minor Symptoms of 115 kV Circuit Breakers

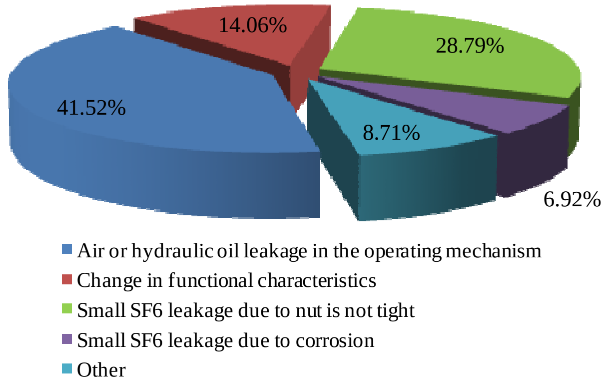

Fig.8. Minor Symptoms of 230 kV Circuit Breakers

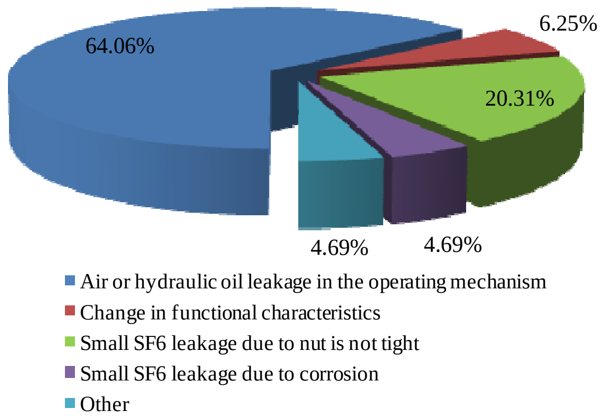

Fig.9. Minor Symptoms of 500 kV Circuit Breakers

4. RESULT DISCUSSION

Statistical failure records of HV circuit breakers are very important for any utility because the fail in equipment can cause a severe damage to the power system. Therefore, this paper presents the analyses on historical failures based on failed-types and symptoms of power circuit breakers in high voltage substations rated as of 115 kV, 230 kV and 500 kV in a Thai utility. The failed-types and symptoms are classified into major and minor failure criteria. For failed-type analysis, failure rates of circuit breakers produced by different manufacturers and installed in three voltage levels are analyzed and ranked. The analyses show the performance of equipment of each manufacturer based on failure frequency per 100 CB-year. The reaults can imply that the manufaturers with the higher failure rates produce the equipment in lower performance. Consequently, the utility shold strickly consider those manufaturers for the future installating of the circuit breakers in substation or even planning of the proper maintenance schedule.

For the symptom analysis, it is similarly classified into major and minor symptoms of the same historical failures of HV circuit breakers in high voltage substations. In major symptom of failure of circuit breakers in all voltage levels is "Does not closed on command". Whereas the minor symptoms of failure are different for each voltage level. For 115 kV circuit breaker, "small SF_6 leakage due to loosen bolt and nutis" is the main cause of minor symptom with less problem in operating mechanism parts due to its small and compact size e.g. motor charge spring. On the contrary, 230 kV and 500 kV circuit breakers, the main cause of minor symptom is “air or hydraulic leakage in operating mechanism” because of their multi-interrupter construction, which requires large size and highly pressurized operating mechanism.

5. CONCLUSION

The historical failure events of circuit breakers in 115 kV, 230 kV and 500 kV, which are scattering and paper-based in nature, are systematically recorded in the central database. After setting up the central database, the number of failure events and service year of each manufacturer are known. Thus, the failure rate of circuit breakers according to each manufacturer can be subsequently calculated. The circuit breakers from manufacturers with high failure rate requires more attention than the one with lower failure rate in term of maintenance action, maintenance plan and spare part management. Moreover, the symptom as major and minor symptoms for all voltage levels is determined. The known symptom from using experiences is used as a valuable lesson to avoid repeated failure. The main symptom is originated from operating mechanism especially 230 kV and 500 kV circuit breakers due to multi-interrupter construction. Hence the operating mechanism should be intensively focused in maintenance in order to improve the reliable operation of this equipment.

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