# Performance Evaluation Based on Symptom, Failed-Type and Obsolescence Criteria of High Voltage Circuit Breaker

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***Abstract*—** The requirement to renovate the deteriorated and aging electrical asset is now playing a significant role on the quality of electrical supply. Thus this paper presents the performance evaluation of 115 kV circuit breaker in power substation. The degraded high voltage circuit breakers should be assessed and clearly identified as supported reasons for planning the renovation task of electrical asset. This performance assessment based on symptom, failed-type and obsolescence criteria are used to clearly identify the visible deterioration. The proposed method was implemented with sixteen circuit breakers in two high voltage substations in Thai electrical utility as examples for illustrating the application of the method. The results show that performances of high voltage circuit breakers are in three stages for healthy, moderate, and risk performance. In the risk stage, the circuit breaker should be intensively cared. The proposed method can be further adapted to other high voltage equipment in power substation.

***Keywords*—** High voltage circuit breaker, symptom, failed-typed, obsolescence, renovation index, performance index

## I. INTRODUCTION

The major equipments in high voltage (HV) substation are power transformer, HV circuit breaker, disconnecting switch, surge arrester and instruments transformer. HV circuit breaker is one of the most importance equipment. It has functions for switching in or disconnecting the operating circuit for maintenance purpose as well as interrupting the fault current for preventing the adverse consequences in power system. The HV circuit breakers with high failure statistic and nearly-reached the end of lifetime should be analysed intensively for preventing unpredictable failure and evaluating their performance in operation. With the known performance, the proper maintenance can be determined in order to save the maintenance costs of utility. Since HV circuit breakers installed in power system are different in number of installed units, manufacturer and technologies, this make it difficult to evaluate their performance. Generally, the performance deterioration of circuit breakers depends on quality of equipment, installation practice, loading stress, maintenance quality, service environment such as temperature, moisture, pollution, and etc. All aforementioned problems mainly effect to the performance of HV circuit breaker as visible degradation. The effects of the visible deterioration can be classified as symptom or sign of failure, failed-type or historical failure experienced from using each model and manufacturer of circuit breaker and obsolescence criteria. These criteria should be evaluated together to determine the performance of HV circuit breaker.

This paper presents the performance evaluation of 115 kV circuit breakers in power substations by classifying symptom, failed-type, and obsolescence aspects. The scoring and weighting techniques are applied in this work for performance evaluation. The obtained results are indicated in term of the renovation index and performance index of HV circuit breaker. Therefore, the properly maintenance schedule, replacement or refurbishment of HV circuit breaker can be reasonably planned.

## II. WORKING PROCEDURE

The working procedure and details of HV circuit breaker performance evaluation are shown in Fig 1. It starts from research and study on performance evaluation of HV circuit breaker, data collection, data classification into symptom, failed-type and obsolescence, analysis of evaluation criteria, results and discussion, and conclusion.

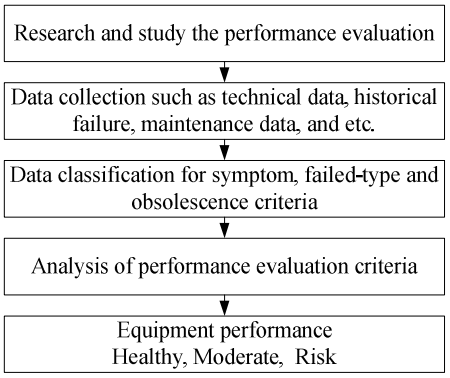



Fig. 1 Working procedure

### *A. Renovation Criteria*

The criteria for renovation of the high voltage circuit breaker in HV substation can be classified into five categories such as age, stress, symptom, failed-type, and obsolescence. The details are described as follows.

*Age* refers to the deterioration of the equipment's strength over the chronological time. Certain materials in the equipment deteriorate over time until some types of failures

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occur. The aging of the equipment can start from the beginning of usage or as it comes out of factory.

*Electrical stress* imposed on equipment during in-service operation can cause parts to fail prematurely e.g. fault level or actual load current higher than equipment rating. Moreover, other form of stress could be caused by external events.

*Symptom* means any signs of degradation that could lead to failure of equipment. These symptoms can be inspected through visual inspection or using diagnostic devices. Some parts of the equipment, when showing the sign of failure or having symptom, could subsequently lead to equipment failure as a whole.

*Failed-type* bases on the statistic data of each equipment model that used to have problems or failures in the past. In order to avoid service interruption, the certainly known failed-type model would be removed or replaced by other more reliable model into the system.

*Obsolescence* such as spare parts unavailability, technology modernization, downtime to repair, and after sale service, are sample criteria of problems in obsolescence of electrical power equipment.

However, this paper focuses on three criteria as symptom, failed-type and obsolescence.

### B. Scoring and Weighting Techniques

The scoring and weighting techniques are in the form of multi-attribute or multi-criterion analysis. It involves identification of the non-monetary factors that are relevant to the project. The allocation of weights to each of them reflects their relative importance. The allocation of scores to each option reflects how it performs in relation to each attribute. The result is a single weighted scored for each option, which may be used to indicate and compare the overall performance of the options in non-monetary terms.

### C. Performance Index Calculation

In this work, the scoring technique is used for classifying the condition of HV circuit breaker into several levels such as healthy, moderate/need caution and risk. The weighting technique is used for ordering an importance of each criterion. Percent factors are obtained by utilized the scoring and weighting factor. The health index (HI) can be achieved by comparing with the percent factors and finally the evaluated condition is presented according to traffic light sign: green as healthy, yellow as moderate/need caution, and red as risk.

The equations of health index and renovation index are shown in Eq. 1 and Eq. 2 respectively [2].

$$HI(\%)=\frac{\sum_{i=1}^{n}(s_i \times w_i)}{\sum_{i=1}^{n}(s_{i,\max} \times w_i)} \times 100 \quad \text{.....(1)}$$

$$RI(\%)=\frac{\sum_{j=1}^{m}(\%HI_j \times W_j)}{\sum_{j=1}^{m}(S_{j,\max} \times W_j)} \times 100 \quad \text{.....(2)}$$

$$PI\ (\%) = 100 - RI(\%) \quad \text{.....(3)}$$

High renovation index refers to the high requirement of equipment renovation. The performance index of equipment is calculated as given in Eq. 3. Similarly, the higher performance index is the better condition.

## III. Performance Evaluation

In order to evaluate the performance of HV circuit breaker in power substation, the scoring and weighting techniques [2] is applied. The equipment scoring and weighting factors are defined by the utility experts' experiences. The different criteria such as symptom, failed-type, and obsolescence criteria are analysed in terms of aforementioned weighting and scoring. Then, the performance evaluation indices of HV circuit breakers can be obtained. The details can be explained below.

### D. Symptom Criterion

For symptom criterion, weighting factors of 11 symptom aspects for HV circuit breaker such as the visual inspection, diagnostic tests, failure frequency, deterioration of steel structure and concrete foundation are shown in Table I whereas scoring factors of those aspects are given in Table II.

TABLE I
WEIGHTING FOR SYMPTOM CRITERION

| Symptom Aspects | Weight |
|---|---|
| a) Visual inspection | 5 |
| b) Contact timing | 10 |
| c) Contact resistance | 10 |
| d) Insulation resistance | 10 |
| e) Dielectric losses | 10 |
| f) Steel structure | 5 |
| g) Concrete foundation | 5 |
| h) Gas Leakage rate (times/year) | 10 |
| i) Cannot operate/close, trip without command (times/year) | 20 |
| j) Dashpot failed / leak (times/year) | 5 |
| k) Air / hydraulic oil leak (times/year) | 10 |

TABLE II
SCORING FOR SYMPTOM CRITERION

| Criteria | Scoring for Symptom Aspects | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| a) | normal | | | | abnormal |
| b) | <10 | | | | ≥ 10 |
| c) | <2 | | | | ≥ 2 |
| d) | <10000 | | | | ≥ 10000 |
| e) | normal | | | | abnormal |
| f) | normal | | rust | | rust and corrosion |
| g) | normal | | cracks | | cracks and collapse |
| h) | ≤ 1 | | 2 | | ≥ 3 |
| i) | 0 | | 1 | | ≥ 2 |
| j) | 0 | | 1 | | ≥ 2 |
| k) | 0 | 1 | 2 | 3 | ≥ 4 |

### E. Failed-Type Criterion

For failed-type criterion, the failure rates must be calculated first in terms of failure frequency per 100 CBs year. The scorings of failed–type aspect are classified into 3 levels depending on the failure rate which are defined in Table III. The mean and standard deviation are used to differentiate the level of failure rate for evaluating performance of HV circuit

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breaker. For example, HV circuit breaker that has failure rate lower than one standard deviation from the mean, this HV circuit breaker has a score "1" as given in low failure rate group. Because of the failed-type criterion has only one aspect, the weighting factor of failure rate is equal to 100%.

TABLE III
SCORING FOR FAILED-TYPE CRITERION

| Criteria | Scoring for Failed-Type Aspects | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Failure rates | Low | - | Medium | - | High |
| | < Mean-SD | - | Mean±SD | - | > Mean+SD |

### F. Obsolescence Criterion

For obsolescence criterion, there are six aspects such as availability of spare part, cost of inspection and maintenance, down time to repair, after sale service quality, technology obsolescence and effort to rebuild or refurbish. Each aspect is weighted and scored as presented in Tables IV and V, respectively, in order to achieve the performance.

TABLE IV
WEIGHTING FOR OBSOLESCENCE CRITERION

| Obsolescence Aspects | Weight |
|---|---|
| a) Availability of spare part | 35 |
| b) Cost of inspection & maintenance (THB/yr) | 15 |
| c) Downtime to repair (hr/times) | 10 |
| d) After sale service quality | 10 |
| e) Technology obsolescence | 20 |
| f) Effort to rebuild/refurbish | 10 |

TABLE V
SCORING FOR OBSOLESCENCE CRITERION

| Criteria | Scoring for Obsolescence Aspects | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| a) | available | available but time consuming | lacking but still produce | lacking/not produce/ modify | unavailable/ cannot modify |
| b) | < 50,000 | | 50,000 - 100,000 | | > 100,000 |
| c) | < 6 | | 6 – 24 | | > 24 |
| d) | good | | moderate | | poor |
| e) | normal | | replaced by new technology | | obsolete/ not support |
| f) | low | | medium | | high |

### G. Overall Performance

For overall renovation criterion, 3 aspects are considered as given in Table VI. Each aspect is weighted as shown in Tables VI and subsequently used to calculate the overall performance.

TABLE VI
WEIGHT RESULTS FOR RENOVATION CRITERIA OF HV CIRCUIT BREAKER

| Renovation Criteria | Overall Weight (%) |
|---|---|
| Symptom | 50 |
| Failed-type | 25 |
| Obsolescence | 25 |

TABLE VII
PERFORMANCE INDEX OF HV CIRCUIT BREAKER

| Performance Index | | |
|---|---|---|
| Healthy | >75% | Green |
| Moderate | 50-75% | Yellow |
| Risk | <50% | Red |

Table VII shows the determination criteria of performance index as colour bands such as, green as good or healthy condition, yellow as moderate or requiring planned maintenance and red as poor or risky condition requiring reparation or renovation as soon as possible.

## IV. RESULTS AND ANALYSIS

### A. Method Implementation of a 115 kV Circuit Breaker

Fig. 2 shows a 115 kV circuit breaker that has been installed in a 115 kV substation since 1976. Currently, its age is 36 years old which is over the end of life. Hence, it should be clearly assessed for renovation planning to prevent catastrophic damage. The mentioned assessment in terms of symptom, failed-type and obsolescence are applied to help the utility for planning the replacement or refurbishment their asset in term of renovation and performance indices.



Fig.2 Example of the aged 115 kV circuit breaker

TABLE VIII
HEALTH INDICES OF SYMPTOM, FAILED-TYPE, AND OBSOLESCENCE CRITERIA

| Symptom Aspects | Weight ($w_i$) | Score ($s_i$) | $w_i$*$s_i$ |
|---|---|---|---|
| Visual inspection | 5 | 1 | 5 |
| Contact timing | 10 | 1 | 10 |
| Contact resistance | 10 | 1 | 10 |
| Insulation resistance | 10 | 1 | 10 |
| Dielectric losses | 10 | 1 | 10 |
| Steel structure | 5 | 5 | 25 |
| Concrete foundation | 5 | 1 | 5 |
| Gas leakage rate | 10 | 1 | 10 |
| Cannot operate / close, trip without command | 20 | 1 | 20 |
| Dashpot failed / leak | 5 | 1 | 5 |
| Air / hydraulic oil leak | 10 | 1 | 10 |
| | Symptom Index (%$HI_S$) | | 24% |
| **Fail-Type Aspects** | **Weight ($w_i$)** | **Score ($s_i$)** | **$w_i$*$s_i$** |
| Failure rates | 100 | 3 | 300 |
| | Failed-Type Index (%$HI_F$) | | 60% |
| **Obsolescence Aspects** | **Weight ($w_i$)** | **Score ($s_i$)** | **$w_i$*$s_i$** |
| Availability of spare part | 35 | 1 | 35 |
| Cost of inspection & maintenance | 15 | 1 | 15 |
| Downtime to repair | 10 | 3 | 30 |
| After sale service quality | 10 | 3 | 30 |
| Technology obsolescence | 20 | 3 | 60 |
| Effort to rebuild/refurbish | 10 | 1 | 10 |
| | Obsolescence Index (%$HI_O$) | | 36% |

The actual condition of this HV circuit breaker is evaluated and transformed to the scoring values of each criterion. The health index of each criterion can be calculated and shown in the Table VIII. The symptom index ($HI_S$), failed-type index ($HI_F$) and obsolescence index ($HI_O$) will be calculated together to find equipment renovation index. Finally, the performance index is calculated as shown in Table IX.

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TABLE IX
OVERALL PERFORMANCE EVALUATION OF A SAMPLE HV CIRCUIT BREAKER

| Performance Criteria | Weight (Wi) | %HI | Wi*%HI |
|---|---|---|---|
| Symptom | 50 | 24 | 1200 |
| Failed-Type | 25 | 60 | 1500 |
| Obsolescence | 25 | 36 | 900 |
| | | Renovation Index | 36% |
| | | **Performance Index** | **64%** |

### *B. Method Implementation of Circuit Breakers in 115 kV Substations*

Table X shows health indices of all renovation criteria and overall performance index of every HV circuit breaker in two substation in Thailand electric utility, which consist of 5 and 11 HV circuit breakers, respectively. HV circuit breakers in Bay 1, Bay 2, Bay 3 and Bay 4 of the first substation are not evaluated since they are in future bay and not constructed yet.

TABLE X
PERFORMANCE EVALUATION OF HV CIRCUIT BREAKERS IN HV SUBSTATIONS

| Device No. | $\%HI_S$ | $\%HI_O$ | $\%HI_F$ | Performance Index (%) |
|---|---|---|---|---|
| 115 kV Circuit Breaker in Substation A | | | | |
| Tie Bay | 20 | 28 | 20 | 78 |
| Bay 5 | 20 | 28 | 20 | 78 |
| Bay 6 | 26 | 36 | 20 | 73 |
| Bay 7 | 20 | 32 | 20 | 77 |
| Bay 8 | 20 | 32 | 20 | 77 |
| 115 kV Circuit Breaker in Substation B | | | | |
| Tie Bay | 20 | 32 | 20 | 77 |
| Bay 1 | 20 | 32 | 20 | 77 |
| Bay 3 | 20 | 32 | 20 | 77 |
| Bay 4 | 22 | 36 | 20 | 75 |
| Bay 5 | 20 | 36 | 20 | 76 |
| Bay 6 | 20 | 36 | 20 | 76 |
| Bay 7 | 20 | 32 | 20 | 77 |
| Bay 8 | 20 | 32 | 20 | 77 |
| Bay 9 | 24 | 36 | 60 | 64 |
| Bay 10 | 26 | 32 | 20 | 74 |
| Bay 11 | 20 | 28 | 100 | 58 |

Fig. 5 and 6 show the overall performance of all HV circuit breakers in both substations. There are four devices in the yellow zone that are circuit breaker CB-Bay 6 in substation A and CB-Bay 9 to 11 in substation B, which are moderate performance. Among those devices, circuit breakers CB-Bay 11 is the worst in performance.

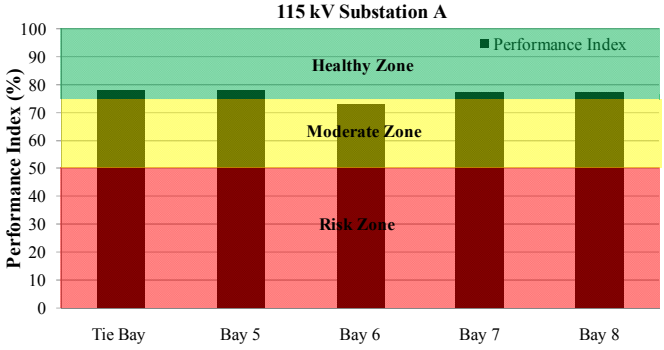



Fig.5 Overall performance of 115 kV circuit breaker in substation A

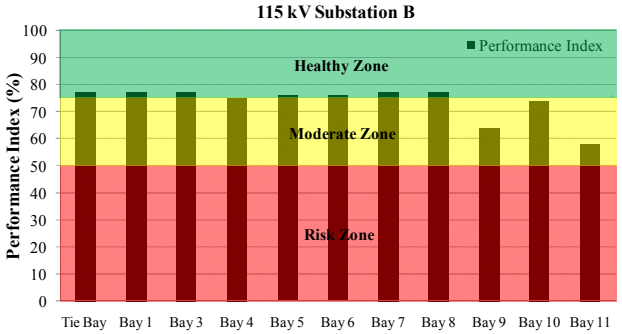



Fig.6 Overall performance of 115 kV circuit breaker in substation B

The poor performance circuit breakers encounter high failure rate experienced by using such model of circuit breaker in the past historical record. Thus those circuit breakers should be carefully focussed and planned for intensive servicing in the next scheduled maintenance in order to prevent the failure occurring in the future.

## V. CONCLUSION

The method to identify the demand for circuit breaker renovation is proposed by using three criteria as symptom, failed-type and obsolescence. For each criterion, the scoring and weighting technique is applied to classify the actual input data to several levels of severity and to assign the degree of importance of each criterion. The comprehensive detail of scoring and assigned weighting of each criterion is presented in this paper. Furthermore, the proposed method is implemented with one circuit breaker to illustrate the application of the method. Then this method is implemented with two substations in Thailand electric utility to evaluate the overall performance index of every circuit breaker in such substations. With the known performance index, the demand for renovation can be reasonably defined with supported information from health index of each criterion. These proposed three criteria will be further combined with the remaining age and stress criteria to achieve the comprehensive evaluation of asset performance. The proposed method will be subsequently adapted to other high voltage equipment in power substation. The obtained result provides significant information to asset manager to plan the renovation task of his own asset.

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