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OPTIMAL BUDGET ALLOCATION STRATEGY BASED ON CONDITION BASED MAINTENANCE FOR POWER DISTRIBUTION SYSTEMS ASSETS: A CASE OF CIRCUIT BREAKERS

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ABSTRACT

This paper develops methods and tools for supporting maintenance management of power distribution system which focused on the circuit breaker (CB). This is done by Multicriteria Decision Making (MDM) process techniques of analytic hierarchy process (AHP) for Condition-Based Maintenance (CBM). There are major issues on large numbers of CB to justify their criticality with budget limits. AHP model applied both qualitative and quantitative criteria to evaluate the conditions of each CB through introduced indices. Simulation AHP tool for maintenance objective and progressive budget optimization (PBO) was developed by using MATLAB® to determine critical CB with budget allocation. The proposed method is utilized on a sample transmission substation for 32 circuit breakers environment using 32 Buses IEEE RBTB model. The results of numerical analysis and progressive allocate tool, shows this method can be employed the prioritized of critical CB in CBM while optimizing the constrained budget for maintenance policy.

1. INTRODUCTION

The power distribution industry has considered for improvement by moving from scheduled maintenance to actual condition maintenance policy and condition-based maintenance (CBM) is one of the best practice solutions especially for circuit breakers (CB). Technology developments on monitoring techniques under various conditions either directly or indirectly affect the maintenance policies (Garzon, 2002; Hoidalen and Runde, 2005). Power system maintenance management has been always major challenges. The operation concerns with a limitation on the annual investment of maintenance and operating costs. There are various types of maintenance models have been implemented in power systems worldwide. For example, condition-based risk maintenance (CBRM),

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reliability-centered maintenance (RCM), time-based maintenance (TBM), and CBM can be considered. These various approaches have particular impacts on power system components (Liu and Huang, 2010; Hinowand and Mevissen, 2011) including service quality. CBM is considered as the most efficient approach for the power distribution system. In terms of financial management, CBs will impact those economic achievements and future management capability in smart environments. The evaluation of health index for equipment to determine the present condition is the key requirement for CBM establishment process for CBs (Galati, *et aI.*, 2009; Schlabbach and Berka, 2001). To make CBM model become effective, it is essential to get data from each CB for analyzing. Real-time data interface, data cleansing, signal processing techniques made the condition monitoring techniques much more practical, easy to implement and automated as well (Kezunovic, *et aI.*, 2005) It is necessary to develop models that convert the condition data or health indices for CB criticality and potential of failure which supports component reliability, probabilistic maintenance models are developed for power transformers and circuit breakers (Jirutitijaroen, and Singh, 2004) to understand the component reliability. These health indexes and potential of failure are illustrated in Figure 1 and 2.

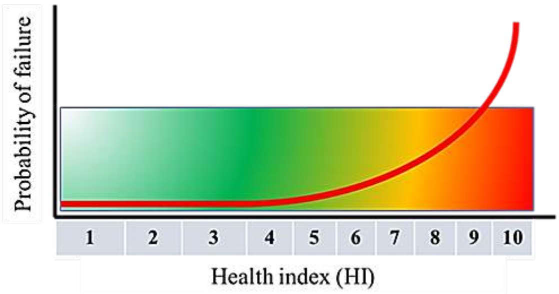

Figure 1: Probability of failure and health index.

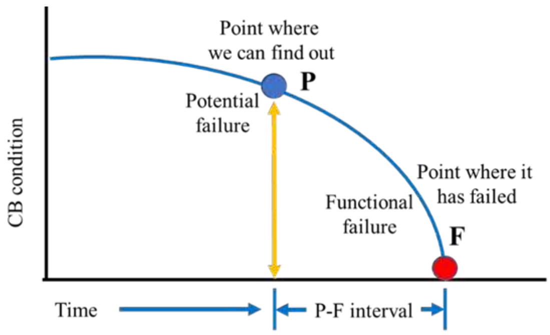

Figure 2: Potential of Failure curve (P-F curve)

In the past decades, there are many available methods using pairwise comparisons with multi-criteria decision-making (MDM) (Keeney and Raiffa, 1976). between finite alternatives or justifications. Saaty (1994) suggests the analytic hierarchy process (AHP) and it becomes a very popular approach to MDM. These involve qualitative and quantitative data. With the use of a reciprocal decision matrix obtained by pairwise comparisons, the information is given in a linguistic form (Saaty,1980; Zahedi, 1986) as a method for MDM. It provides a way of breaking down the general method into a hierarchy of sub-problems, which are easier to evaluate or justify those complexity criteria. It is necessary to evaluate individual alternatives, deriving weights for the criteria, constructing the overall rating of the alternatives and identifying the most prioritized sequences.

In complex environments, decision making, under multi-alternatives and criteria, is important for modern management problems (Chen, 2010), (Dong, *et al.*, 2011). AHP has been used to analyze the related problem for CB conditions. In response to health indices perspective and in accordance with the criticality assessment of CBs in (Razi-Kazemi, *et al.*, Apr 2013). the paper had formulated the AHP model related to the priority assessment of online monitoring (OLM) investment for power distribution system CBs using a practical qualitative-quantitative model approach. There was a further model has evaluated the critical CB including conventional allocation algorithm, the CBs are selected from the ranked CBs. To analyst the prioritization of CBs and allocated budget for monitoring the critical CB. (Razi-Kazemi, *et al.*, Jul. 2013). This original allocation method will allocate all amount of budget using convention sequential budget allocation process. It uses counter CB.*(i)* to increment one step at a time for sequence loops of each critical CB. However, there are some conditions where the remain balance is not sufficient for the current CB,*(i)* but it is possible to allocate to the next CB,*(i+n)*. These are the main gap for improvement by applying progressive budget allocation method. This initiative solution will look forward to CB,*(i+n)* or advanced sequences for possible optimal budget allocations.

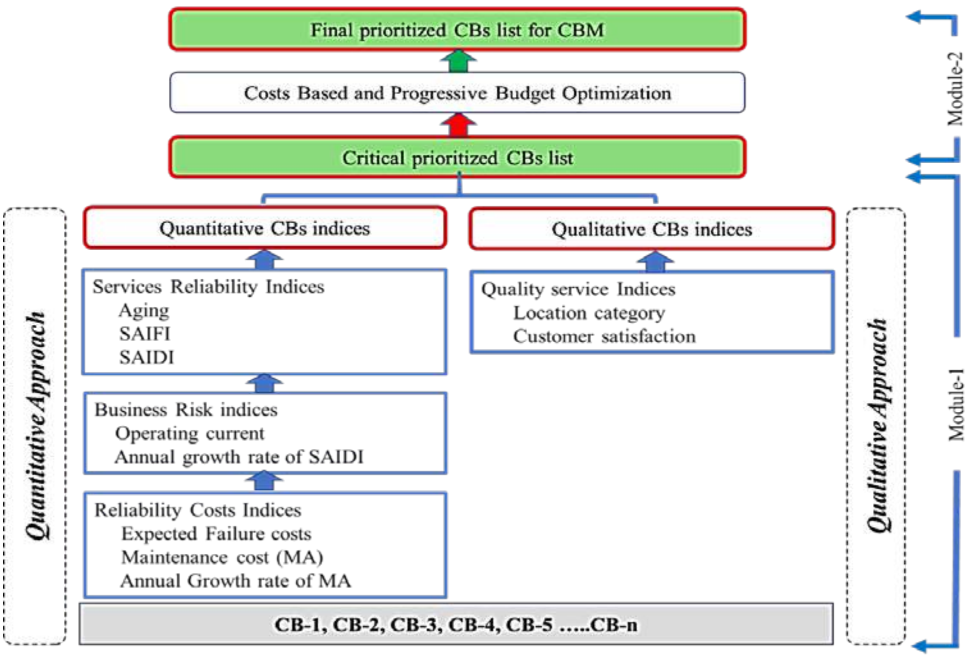

Figure 3: Proposed AHP on CBM for CB prioritization and optimal budget scheme.

2. PROPOSE MODEL FOR PRIORITIZATION AND OPTIMAL BUDGET MODEL

This work develops methods and tools to supports CB maintenance for power systems, via the use of the MDM Process techniques using AHP in CBM. AHP methodology is a comparison of the pair-wise matrix from criteria to determine normalize and final weight which can justify CB conditions. CBM model consists of real-time data monitoring and predictive maintenance in related to the potential of failure. This formulated AHP model using MATLAB 2008 to evaluate CB criticality and priority ranking then to analyze for budget optimization in according to these prioritized CB. This simulation applies to a sample transmission substation for 32 circuit breakers environment using 32 Buses IEEE RBTB model. An optimization model can apply "what if Scenario" in order to optimize the constrained budget. The formulation consists of two main modules

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in prioritization and optimal budget model which can be demonstrated in Figure 3.

2.1 MODULES 1: QUALITATIVE AND QUANTITATIVE SCHEME

In module 1, it is AHP function based on CBM criterion. This objective is to determine critical CB using a practical qualitative-quantitative model approach. The qualitative approach method which cannot be easily mathematically modeled will be applied including quantitative model through a different definable group of criteria. This formulation will enable AHP to calculate total indices and finalize CB critical weight which related to pair-wise criteria of 1) Quality service indices, 2) Service reliability indices, 3) Business risk indices and 4) Reliability costs indices.

2.2 MODULES 2: PRIORITIZATION AND OPTIMAL SCHEME

This module uses progressive budget optimization based on "what if scenario" in order to maximize utilization of constrains budget. These scenarios will allow maintenance operation and planning to exercise or make simulation in different budget conditions that satisfy management policy. The budget will allocate to high prioritized CB in the first order and continue with the progressive method until the budget is fully utilized. The qualitative criteria linked with the AHP for CBM problem, as multiple criteria decision-making tool and budget utilized by progressive budget optimization (PBO). The qualitative approach to support service quality base indices is considered by customer category and customer satisfaction from the customers' survey report. The second group is the quantitative approach. These aspects of criteria are treated via proposed services reliability and costs orientation indices. The proposed indices are classified by Aging of equipment, different loads importance of service category, System Average Interrupted Frequency Index (SAIFI), System Average Interrupted Duration Index (SAIDI), Operating current, load interruption or Failure costs, Maintenance cost and Annual accumulated of maintenance cost.

2.3 THE PRIORITY ASSESSMENT ALGORITHM

Figure 3, the weights help to prioritize CBs. To assess the condition of CBs, qualitative approach is used with AHP. To determine of CB's conditions, the quantitative approach is employed for influence on the overall system reliability via the proposed indices. To consider the cumulative weight of critical CB conditions to get an optimal and practical solution, two qualitative and eight quantitative weighting coefficients are combined and developed, based on Equations (1), (2), and (3).(Razi-Kazemi et al., 2013)

$$W_{CB,i} = \omega_{QT}\, W_{QT,CB,i} + \omega_{QL}\, W_{QL,CB,i} \qquad (1),$$

where

$W_{CB,i}$ = Total cumulative weight of the i^{th} CB via the reliability indices;

$W_{QT,CB,i}$ = Quantitative weight of the i^{th} CB through the reliability indices;

ω_{QT} = Normalization coefficient specified for the quantitative weight;

$W_{QL,CB,i}$ = Qualitative weight of the i^{th} CB using AHP;

ω_{QL} = Normalized coefficient specified for qualitative weight.

Conditions $\omega_{QT} + \omega_{QL} = 1$

2.4 AHP-BASED QUALITATIVE DECISION-MAKING

MDM is complex environments of power distribution systems, consisting of multiple alternatives and criteria to be considered. Being one of the most applicable modern management problems (Kezunovic, *et al.*, 2005b), AHP can deal with critical CB and maintenance prioritization problem, based on the relative importance or critical comparisons of the criteria. The AHP allows decision maker capability to focus on parameters via a comparison (for instance based on CBM details). It is not only easy to use, but also is more efficient and gives better outcome. More discussions are given in e.g. Kezunovic, *et al.* (2005a). The uncertainty criteria can be formulated using AHP for qualitative and qualitative criteria. The AHP can deal with complex criteria that the three main stages can apply.

Step. I: Hierarchical Modeling

The problems and objectives must be clearly defined at the beginning of the first stage, the key decision maker has to analyze overall criteria or factors that concerned with objectives then breakdown the whole problem into simple parts or criteria in a manner that all the decision problem features could be embraced in a hierarchical structure in Figure 3.

Step. II: Pairwise Comparison and Priority Investigation

For the second stage with pairwise comparison, the key decision makers need to compare those criteria depended on expertise and available information. Questionnaires survey can be prepared for distribution to a involved number of experts and engineers in the MDM process. To complete the comparison matrices, the fuzzy linguistic variables are employed. to simplify the process, each fuzzy number is assumed as triangular or absolute mean value. For common applicability, a triplex *(l,m,u)* is defined in which *l,m,u* refer to the membership function mean, lower, and upper bounds (Keeney and Raiffa, 1976)

$$\mu(x) = \begin{cases} \frac{x-l}{m-l} & l < x < m \\ \frac{u-x}{u-m} & m < x < u \\ 0 & otherwise \end{cases} \qquad (2)$$

As a result of membership function, the linguistic variables in conventional AHP change into the fuzzy linguistic of importance variables whose definitions are provided in Table 1.

Table 1: Relative importance variables for pair-wise comparison

Scale	Definition	Pair-wise relative importance
1	Equally importance	1,1,2
3	Modulate more importance	2,3,4
5	Strongly more importance	4,5,6
7	Very strongly more importance	6,7,8
9	Extremely more importance	8,9,9

Reference to the pair-wise relative of importance, the key decision makers can make subjective judgments, uncertainty and imprecision of the specialists can be easily dealt with alternative and specific criteria especially concerned with CBM, it leads to more reliable and accurate final results. When finding the final weight of each criterion through fuzzy weighting, the results obtained from a number of experts collaborating in the MDM process would be involved as shown in the following (3). In these equations, the subscripts denote the i^{th} and j^{th} criterion, and k^{th} expert; *n* is also representative of the number of experts involved in MCDM problem

$$\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij}) = [l_{ij}, u_{ij}] \quad (3),$$

For each element of the hierarchy structure, all the associated elements in the sub-criteria hierarchy are compared in pairwise comparison matrices as shown in (4).

$$\mathbf{A} = \begin{bmatrix} 1 & W1/W2 & W1/W3 & .... & W1/Wn \\ W2/W1 & 1 & W2/W3 & .... & W2/Wn \\ W3/W1 & W3/W2 & 1 & .... & W3/Wn \\ : & : & : & : & : \\ Wn/W1 & Wn/W2 & Wn/W3 & .... & 1 \end{bmatrix} \quad (4),$$

where *A* = comparison pairwise matrix, and *W1, W2, W3,..,Wn* are weights of element *1, 2, 3,.., n*. To determine the relative preferences in matrix A for two elements for the hierarchy, the semantical scale is used with the rate values from 1 to 9.

Step. III: Checking for Consistency

An important issue in MDM process in comparison model is the consistency of parameters comparisons done by different experts or categories. Normally, we cannot make perfect judgments. Having the framed weighting matrices, it is then possible to verify the consistency of the qualitative or quantitative weighting and comparison in AHP using a consistency index (CI), (Saaty, 1980).

$$CI = \frac{\lambda max - 1}{n - 1} \quad (5),$$

where λmax and, *n* respectively, denote the maximum eigenvalue and the order of comparison matrices. The consistency ratio (CR) can be obtained via (6)

$$CR = \frac{CI}{RI} \quad (6),$$

where the random consistency index (RI) can be obtained through (Saaty, 1994), Once the CR becomes lower than 0.1, the consistency of the expert knowledge would be confirmed. Otherwise, the source(s) or pair-wise criteria of inconsistency must be re-identified and resolved again. Then, rerun the whole analysis process.

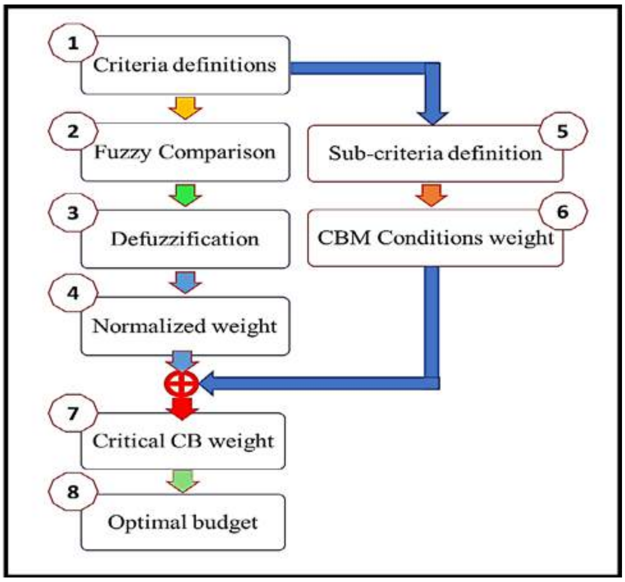

Figure 4: AHP tool and budget optimal process flow.

3. AHP TOOLS AND BUDGET OPTIMAL SIMULATION PROCESS

The AHP tools and budget optimization process starts from the criteria definition until it finalizes the budget. Figure 1 illustrates the flowchart of the developed program for modeling AHP as the basic form of a hierarchical model of multiple criteria decision-making. The ultimate objective aims to analyze and identify those prioritized critical circuit breakers based on their actual conditions and budget allocation will be optimal using progressive budget optimization (PBO) method in the final stage. This initiative can be achieved in the following eight processing steps as shown in Figure 4.

These AHP tools and budget optimal simulation model in Figure 5 have eight processing steps to indicate critical CB and make utilization of constrains budget. All processes can be described as following details.

3.1 PROCESS#1: CRITERIA DEFINITION AND PROBLEM HIERARCHICAL MODELING

Many senior engineers, with experience in power distribution system maintenance, give personal interviews to collect data as pairwise comparison matrices weights of the AHP process and correspond with CBM criteria.

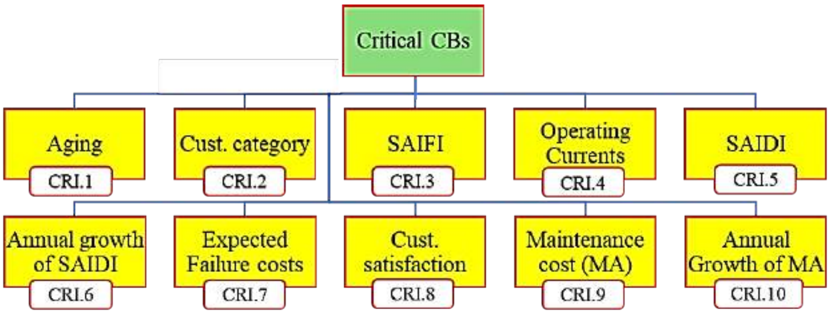

Figure 5: AHP criteria in accordance with CBM parameters.

Information in Figure 5, indicates a total of 10 criteria for indices calculation. It consists of 2 qualitative and 8 quantitative comparison criteria which describe as follows:

Criterion#1: Lifetime, Aging (Quantitative)

Circuit breakers life-time or aging based on installation date are classified each 4 years steps into 5 ranges of 20 years lifetime expectation and defined as 3, 5, 7 and 9 consecutively. These classifications of aging importance are summarized in Table 2,

Table 2: Aging

Criteria-1	**Aging (Year)**				
Value	1.00-4.00	4.01-8.00	8.01-12.00	12.01-16.00	16.01-20.00
Importance	1	3	5	7	9

Criterion#2: Customer Category (Qualitative)

These are the category of the physical location of the customer's area which circuit breakers are installed. Table -3 has classified into 6 categories based on the nature of the customers' environment. There are residential, commercial, industrial, agriculture, government and priority categories. The importance's criteria are classified by an average of revenue contributions ratio in Provincial Electricity Authority (PEA) annual reports.

Table 3: Customer category

Criteria.2	**Customer category**					
Value	Residential	Commercial	Industrial	Agriculture	Government	Priority
Importance	5	7	9	3	1	9

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Criterion#3: SAIFI – Interruption Frequency Index (Quantitative)

System Average Interruption Duration Index (SAIDI) created by Institute of Electrical Electronics Engineers (IEEE). It is the system index of the average frequency of interruptions in power supply which will indicate power system reliability. This is commonly used to measure the power distribution system reliability indicator by electric power utilities. SAIFI is determined by the average number of interruptions that a customer experiences as

$$\text{SAIFI} = \frac{\sum \lambda_i N_i}{N_T} \quad (7),$$

where λ_i, N_i, and N_T are the failure rate, the number of customers for location i, and the total number of customers served, respectively.

SAIFI is measured in units of interruptions per customer, over the course of a year. From the PEA annual 2017 report, the median SAIFI value for service quality utilities is 5.17 interruptions per customer, as classified in Table 4.

Table 4: SAIFI Interruption Frequency indicator

Criteria-3	SAIFI-System Average Interrupted Frequency Index (T/P/Y)				
Value	< 2.00	2.01-4.00	4.01-6.00	6.01-8.00	8.01-10.00
Importance	1	3	5	7	9

Criterion#4: Operating currents (Quantitative)

This index is considered as one of the critical criteria due to the tier level of Circuit Breaker in a network. The top tier level of the network will handle a large amount of operating current and totally having more impact on the numbers of customer. These have classified the operating current in Table 5, starting from 500A to 20KA into 5 fits of the rage of importance.

Table 5: Operating current index

Criteria-4	Operating Currents Rate (Amp)				
Value	<=500A	>500A<2KA	>2KA-5KA	>5KA<=10KA	>10KA<=20KA
Importance	1	3	5	7	9

Criterion#5: SAIDI – Interrupted Duration index (Quantitative)

As a reliability indicator for electric power utilities, the System Average Interruption Duration Index (SAIDI), the average outage duration for each customer served, can be calculated as

$$\text{SAIDI} = \frac{\sum U_i N_i}{N_T} \quad (8),$$

where ***Ui*** is the number of customers. ***N*** is the annual outage time for location *i*. *T* is the total number of customers served.

SAIDI has units minutes or hours, over a year course. From PEA annual report 2016, the service quality utilities median SAIDI value is 153.13 minutes/customer/year.

Table 6: SAIDI failure rate

Criteria-5	SAIDI-System Average Interrupted Duration Index (M/P/Y)				
Value	< 120.00	120.01-140.00	140.01-160.00	160.01-180.00	180.01-200.00
Importance	1	3	5	7	9

Table 6 shows classification of SAIDI indicator is starting from 120 to 200 with 20 in ranging and defining relative importance numbers of SAIDI ranges are 1,3,5,7 to 9 respectively. This defined table can represent the importance of SAIDI failure rate.

<u>Criterion#6</u>: ASAIDI – Annual accumulated SAIDI (Quantitative)

These are compared the value of SAIDI history, its accumulated records for at least 5 years. The comparison of annual growth rate in Table 7 has considered between 1 to 10 percent variances with 3% in ranging steps.

Table 7: Annual SAIDI growth rate

Criteria-6	**SAIDI-Annual growth (%)**				
Value	<=2	2.01<=4.00	4.01<=6.00	6.01<=8.00	8.01<=10.00
Importance	1	3	5	7	9

<u>Criterion#7</u>: Failure cost (Quantitative)

This failure cost is classified by expected failure costs based on penalty or claim value from customer's categories. This claimed amount is calculated by rational of annual revenue from each customers category reference in Table 8.

Table 8: Failure costs

Criteria-7	**Failure costs (Bahts)**				
Value	<=250K	250.01K<=500K	500.01K<=750K	750.01K<=1M	1.01M<=1.25M
Importance	1	3	5	7	9

Note: USD1.00 ≈ 30Bahts.

<u>Criterion#8</u>: Customer Satisfactions (Qualitative)

This is the criteria of a summary report of a customer satisfaction survey from each customer category. The results of each group of customers are indicated in respects to the nature of their interesting. For example, in case of power interrupted for 5 minutes of industry category will have fewer complaints than residential area due to a number of customers, however, the failure cost may have more impacts on the industry group. This survey details could determine how customers justify the overall services. Table 9 can indicate satisfaction scale.

Table 9: Customer satisfactions

Criteria-8	**Customer satisfactions**				
Value	Very satisfy	Satisfy	Fair	Unsatisfied	Very unsatisfied
Importance	**1**	**3**	**5**	**7**	**9**

<u>Criterion#9</u>: Maintenance cost (Quantitative)

This index represents the amount of maintenance cost required to maintain circuit breakers based on operation & maintenance procedure and policy. It classifies these maintenance value in percentage compared to the average of newly installed CB's asset costs. (The average asset cost of new CB is 800,000 Bahts). The criteria are starting from 8K as normal index value which is considered to 1. and for incremental of 24K,40K,80K,120K cab be defined as 3,5,7 and 9 consecutively. Criteria details are summary in Table 10.

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Table 10: Maintenance costs

Criteria-9	**Maintenance costs (Bahts)**				
Value	<= 8 K	>8.01K<=24K	>24.01K<=40K	>40.01K<=80K	>80.01K<=120K
Importance	1	3	5	7	9

<u>Criterion#10</u>: Annual growth of maintenance cost (quantitative)

These are compared the value of the accumulated value of maintenance history records for at least 5 years. The growth rate has considered between 1 to 10 percent as shown in Table 11.

Table 11: The annual maintenance growth rate

Criteria-10	**Annual maintenance growth (%)**				
Value	<=2	2.01<=4.00	4.01<=6.00	6.01<=8.00	8.01<=10.00
Importance	1	3	5	7	9

These total 10 criteria will use for pair-wise comparison matrix and AHP weight normalization in order to finalize the critical weight of each CB in the power distribution system. The total accumulated weight of critical can determine the ranking of prioritizing CB.

3.2 Process#2: Fuzzy importance pair-wise comparison matrix

To make a fuzzy comparison matrix in reference to importance pair-wise comparison criteria. It calculates all related to definition criteria from processing step-1. There are two groups of pair-wise comparison summary of 10 criteria to be analyzed.

3.3 Process#3: Defuzzification of importance pair-wise comparison

To perform defuzzification of importance pair-wise comparison in comparison matrix format from processing#2. This calculation will solve the compared matrix by eigenvector multiplication and the average mean value from each criterion that shows in Table 12.

3.4 Process#4: Obtain normalized weight

This process will obtain normalized weight for calculation factors in accordance with 10 criteria definitions in Tables 13 and 14. It is also necessary for consistency check and makes sure the consistency should not exceed acceptance value.

Table 12: Mean average and the total value of the pair-wise comparison matrix.

Power-Sqr	Aging	C.categ	SAIFI	O.curr	SAIDI	ASAIDI	FC	C,Satis	MA	AMA
Aging	1.0000	3.0000	3.0000	5.0000	3.8730	3.8730	5.9161	6.7082	5.9161	5.0000
C.categ	0.3333	1.0000	3.0000	3.0000	5.0000	3.0000	3.8730	5.1962	5.0000	7.9373
SAIFI	0.3333	0.3333	1.0000	3.0000	3.0000	3.0000	3.8730	5.0000	4.5826	7.0000
O. Curr	0.2000	0.3333	0.3333	1.0000	3.0000	3.0000	3.8730	3.0000	3.8730	5.9161
SAIDI	0.2582	0.2000	0.3333	0.3333	1.0000	3.0000	3.0000	3.0000	3.0000	5.0000
ASAIDI	0.2582	0.3333	0.3333	0.3333	0.3333	1.0000	3.0000	3.0000	3.0000	3.0000
FC	0.1690	0.2582	0.2582	0.2582	0.3333	0.3333	1.0000	3.0000	3.8730	3.0000
C.Satis.	0.1491	0.1925	0.2000	0.3333	0.3333	0.3333	0.3333	1.0000	3.0000	3.0000
MA	0.1690	0.2000	0.2182	0.2582	0.3333	0.3333	0.2582	0.3333	1.0000	3.0000
AMA	0.2000	0.1260	0.1429	0.1690	0.2000	0.3333	0.3333	0.3333	0.3333	1.0000
SUM	3.0702	5.9766	8.8193	13.6854	17.4063	18.2063	25.4599	30.5710	33.5780	43.8533

Table 13: Mean average and defuzzification value of pair-wise comparison matrix.

Ratio	Aging	C.Categ	SAIFI	O.curr	SAIDI	ASAIDI	FC	C,Satis	MA	AMA	Rw-sum	Weight
Aging	0.3257	0.5020	0.3402	0.3654	0.2225	0.2127	0.2324	0.2194	0.1762	0.1140	2.71042	0.27104
C.Categ	0.1086	0.1673	0.3402	0.2192	0.2873	0.1648	0.1521	0.1700	0.1489	0.1810	1.93929	0.19393
SAIFI	0.1086	0.0558	0.1134	0.2192	0.1724	0.1648	0.1521	0.1636	0.1365	0.1596	1.44585	0.14458
O. Curr	0.0651	0.0558	0.0378	0.0731	0.1724	0.1648	0.1521	0.0981	0.1153	0.1349	1.06941	0.10694
SAIDI	0.0841	0.0335	0.0378	0.0244	0.0575	0.1648	0.1178	0.0981	0.0893	0.1140	0.82127	0.08213
ASAIDI	0.0841	0.0558	0.0378	0.0244	0.0192	0.0549	0.1178	0.0981	0.0893	0.0684	0.64982	0.06498
FC	0.0551	0.0432	0.0293	0.0189	0.0192	0.0183	0.0393	0.0981	0.1153	0.0684	0.50502	0.05050
C. Satis	0.0486	0.0322	0.0227	0.0244	0.0192	0.0183	0.0131	0.0327	0.0893	0.0684	0.36881	0.03688
MA	0.0551	0.0335	0.0247	0.0189	0.0192	0.0183	0.0101	0.0109	0.0298	0.0684	0.28882	0.02888
AMA	0.0651	0.0211	0.0162	0.0124	0.0115	0.0183	0.0131	0.0109	0.0099	0.0228	0.20130	0.02013
											10.00000	1.00000

Table 14: Normalize weight of AHP indices calculation.

Normalize weight	
Aging	0.2710419
Customer Category	0.1939288
SAIFI	0.1445845
Operating Current	0.1069413
SAIDI	0.0821269
ASAIDI	0.0649819
Failure cost	0.0505021
Customer Satisfaction	0.0368805
MA	0.0288824
AMA	0.0201297
	1.0000000

In normalization process, it is also necessary to check consistency ratio (CR) that calculated from equation (6), Consistency index (CI) is divided by random consistency index (RI) indicate in Table 15. (Saaty, 1994). The CR value should exceed 0.1.

Table 15: Mean average and total value of the pair-wise comparison matrix.

Consistency	Row-sum	MMULT	λmax
Aging	2.71042	32.08734	1.1839
Category	1.93929	23.35851	1.2045
SAIFI	1.44585	17.14985	1.1861
Opr Curr	1.06941	12.52499	1.1712
SAIDI	0.82127	9.19127	1.1192
ASAIDI	0.64982	7.20009	1.1080
Failure_cost	0.50502	5.43261	1.0757
Cust Satisf	0.36881	3.92077	1.0631
MA	0.28882	3.07404	1.0643
AMA	0.20130	2.14343	1.0648
Criteria	10.00000	Sum	11.2408

Table 16: Random consistency index (RI).

n	1	2	3	4	5	6	7	8	9	10	11
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

The constant value of RI is given in Table 16 by Saaty (Saaty, 1994) to make the calculation for consistency check and a total of 10 criteria will have RI for 1.49. Table 17 shows CR calculates in the AHP model is 0.0925 which is less than 0.1. It means the AHP criterion is accepted.

Table 17: Consistency Ratio

CI =	0.1379
RI =	1.4900
CR =	0.0925

3.5 PROCESS#5: DEFINE SUB-CRITERION

This process is defining sub-criterion of each CB based on 10 criterions in step-1. The overall criteria are references to all criteria in processing step-1, the same classification details will be used for sub-criterion. It consists of 2 qualitative and 8 quantitative criteria, details are in Table 18.

Table 18: Sub-criteria definitions

Criteria	Aging	Customer Category	SAIFI	Operate Current	SAIDI	ASAIDI	FC	Customer Satisfy	MA	AMA
Normalize	0.27104	0.19393	0.14458	0.10694	0.08213	0.06498	0.05050	0.03688	0.02888	0.02013
CB1	5	3	1	3	9	3	1	3	9	3
CB2	5	9	3	3	7	3	1	3	9	3
CB3	5	3	3	5	5	3	3	3	4	3
CB4	7	3	3	5	5	3	3	5	7	3
CB5	9	5	5	1	3	5	5	5	3	5
CB6	5	7	5	1	7	5	5	5	3	5
CB7	9	3	5	5	5	5	3	7	5	5
CB8	9	5	3	5	7	3	5	7	7	1
CB9	3	1	3	9	5	3	7	3	7	1
CB10	3	3	3	5	7	5	7	3	7	3
CB11	9	5	3	5	3	5	3	5	9	3
CB12	9	7	5	5	5	1	5	5	9	3
CB13	9	7	5	3	5	1	9	1	9	5
CB14	1	9	7	3	7	3	3	1	3	5
CB15	5	3	7	3	7	3	5	1	5	7
CB16	5	5	7	5	3	5	1	3	6	5
CB17	5	7	9	5	1	5	1	3	6	3
CB18	7	7	9	5	3	3	3	5	9	5
CB19	7	5	9	3	3	3	3	5	5	7
CB20	7	3	5	3	3	7	3	5	7	7
CB21	7	1	5	7	3	9	5	3	7	9
CB22	1	5	3	5	5	7	7	3	5	7
CB23	1	1	3	5	3	3	9	3	5	5
CB24	1	3	3	5	5	5	3	1	7	3
CB25	5	5	3	3	7	5	1	1	3	3
CB26	5	7	3	3	7	3	1	1	3	5
CB27	5	9	1	3	9	3	1	5	5	3
CB28	5	3	1	5	9	3	5	5	5	3
CB29	5	3	3	5	9	3	5	7	7	5
CB30	5	5	3	7	9	3	7	9	5	5
CB31	7	7	5	7	9	3	3	9	7	3
CB32	3	3	5	5	9	3	5	7	5	3

3.6 PROCESS#6: DETERMINE IMPORTANCE PAIRWISE COMPARISON SUB-CRITERIA

These are the classification to determine importance pairwise comparison sub-criteria in related to definition criteria from Step 5. All sub-criterion of each CB should reflect on their actual conditions. For example, Aging period, Operating current and Maintenance budget required for the particular CB.

3.7 PROCESS#7: CALCULATE FINAL WEIGHT INDICES

Make calculation the compared matrix with normalized weight (Step-4) and actual CB criteria (Step-6) to obtain final weight indices of each CB, then classify priority or ranking CB in accordance with their total indices value. The higher indices value means that particular CB will have a higher potential of failure or become most critical CB. In Table 19, it has illustrated that CB-31 is the most critical based on accumulated condition indices and must be at first priority. CB-12 and CB-18 have second and third prioritize respectively for ranking sequences.

3.8 PROCESS#8. PROGRESSIVE BUDGET OPTIMIZATIONS

These are a very important step to perform budget allocation to high ranking or prioritized CB by using progressive budget optimization model. This process allows constrains budget to exercise with "what-if scenario" in order to fully utilize the annual budget.

Table 19: Calculation indices and total CB weight

CB No	Aging	Customer Category	SAIFI	Operate Current	SAIDI	ASAIDI	FC	Customer Satisfy.	MA	AMA	Total Weight
1	1.35521	0.58179	0.14458	0.43375	0.73914	0.19495	0.05050	0.11064	0.25994	0.06039	3.93090
2	1.35521	1.74536	0.43375	0.43375	0.57489	0.19495	0.05050	0.11064	0.25994	0.06039	5.21938
3	1.35521	0.58179	0.43375	0.72292	0.41063	0.19495	0.15151	0.11064	0.11553	0.06039	4.13732
4	1.89729	0.58179	0.43375	0.72292	0.41063	0.19495	0.15151	0.18440	0.20218	0.06039	4.83981
5	2.43938	0.96964	0.72292	0.14458	0.24638	0.32491	0.25251	0.18440	0.08665	0.10065	5.47203
6	1.35521	1.35750	0.72292	0.14458	0.57489	0.32491	0.25251	0.18440	0.08665	0.10065	5.10422
7	2.43938	0.58179	0.72292	0.72292	0.41063	0.32491	0.15151	0.25816	0.14441	0.10065	5.85728
8	2.43938	0.96964	0.43375	0.72292	0.57489	0.19495	0.25251	0.25816	0.20218	0.02013	6.06851
9	0.81313	0.19393	0.43375	1.30126	0.41063	0.19495	0.35351	0.11064	0.20218	0.02013	4.03411
10	0.81313	0.58179	0.43375	0.72292	0.57489	0.32491	0.35351	0.11064	0.20218	0.06039	4.17811
11	2.43938	0.96964	0.43375	0.72292	0.24638	0.32491	0.15151	0.18440	0.25994	0.06039	5.79323
12	2.43938	1.35750	0.72292	0.72292	0.41063	0.06498	0.25251	0.18440	0.25994	0.06039	6.47558
13	2.43938	1.35750	0.72292	0.43375	0.41063	0.06498	0.45452	0.03688	0.25994	0.10065	6.28116
14	0.27104	1.74536	1.01209	0.43375	0.57489	0.19495	0.15151	0.03688	0.08665	0.10065	4.60776
15	1.35521	0.58179	1.01209	0.43375	0.57489	0.19495	0.25251	0.03688	0.14441	0.14091	4.72739
16	1.35521	0.96964	1.01209	0.72292	0.24638	0.32491	0.05050	0.11064	0.17329	0.10065	5.06624
17	1.35521	1.35750	1.30126	0.72292	0.08213	0.32491	0.05050	0.11064	0.17329	0.06039	5.53876
18	1.89729	1.35750	1.30126	0.72292	0.24638	0.19495	0.15151	0.18440	0.25994	0.10065	6.41680
19	1.89729	0.96964	1.30126	0.43375	0.24638	0.19495	0.15151	0.18440	0.14441	0.14091	5.66451
20	1.89729	0.58179	0.72292	0.43375	0.24638	0.45487	0.15151	0.18440	0.20218	0.14091	5.01600
21	1.89729	0.19393	0.72292	1.01209	0.24638	0.58484	0.25251	0.11064	0.20218	0.18117	5.40395
22	0.27104	0.96964	0.43375	0.72292	0.41063	0.45487	0.35351	0.11064	0.14441	0.14091	4.01235
23	0.27104	0.19393	0.43375	0.72292	0.24638	0.19495	0.45452	0.11064	0.14441	0.10065	2.87319
24	0.27104	0.58179	0.43375	0.72292	0.41063	0.32491	0.15151	0.03688	0.20218	0.06039	3.19600
25	1.35521	0.96964	0.43375	0.43375	0.57489	0.32491	0.05050	0.03688	0.08665	0.06039	4.32658
26	1.35521	1.35750	0.43375	0.43375	0.57489	0.19495	0.05050	0.03688	0.08665	0.10065	4.62473
27	1.35521	1.74536	0.14458	0.43375	0.73914	0.19495	0.05050	0.18440	0.14441	0.06039	5.05270
28	1.35521	0.58179	0.14458	0.72292	0.73914	0.19495	0.25251	0.18440	0.14441	0.06039	4.38030
29	1.35521	0.58179	0.43375	0.72292	0.73914	0.19495	0.25251	0.25816	0.20218	0.10065	4.84126
30	1.35521	0.96964	0.43375	1.01209	0.73914	0.19495	0.35351	0.33192	0.14441	0.10065	5.63529
31	1.89729	1.35750	0.72292	1.01209	0.73914	0.19495	0.15151	0.33192	0.20218	0.06039	6.66989
32	0.81313	0.58179	0.72292	0.72292	0.73914	0.19495	0.25251	0.25816	0.14441	0.06039	4.49032

1) Progressive budget optimization

Proposed progressive budgeting optimization model will analyze available balance budget to be allocated for next sequence (***i***+*1*) to (***i***+n) or until the available amount is less than minimum maintenance amount, or could not match to next required amount, or become less than or equal to zero. There is the special condition for this procedure to determine the next (***i***+1) sequence item which should not be importance CB based on the operation current and expected highly failure cost. In case of this condition has founded then the system will not allocate the available balance budget to next sequence but it will suggest the extra amount required in order to minimize operational risk. The formulate equations of the progressive budget optimization model is illustrated in (9),(10) and (11).

$$Maximum \quad F(x) = A - \sum_{i=1}^{m}(CB_i) \tag{9}$$

where

$$A - \sum_{i=1}^{m}\left(CB_i \right) \leq CB.MA_{min} \tag{10}$$

or

$$A - \left[\sum_{i=1}^{m} \ \sum_{n=1}^{m}(CB_{i+n}) \ \right] \leq CB.MA_{min} \tag{11}$$

Where *F(x)* is the optimize function of budget allocation,

A is the constrain budget or budget allowance, *i* is a sequence number of prioritized circuit breakers,

m is the maximum sequence number of prioritized circuit breakers.

n is an advanced sequence number *(i+n, m)* of prioritized circuit breakers.

CBi is the budget required for prioritized circuit breakers sequence *(i) or (i+n).*

CB.MAmin is the minimum costs required for CB maintenance amount.

Condition: *Progressive counter will proceed if operating current and Failure cost is low.*

(CB,i will increase if (CRI,4 + CRI,7) < Strongly more importance index)

1) Conventional budget allocation

Conventional budget allocation process details are calculated by loops sequence step.

Table 20: Conventional budget allocation

Conventional budget allocation (Bahts)										
A	CB No	31	12*	18	13	8*	7	11	19	30*
B	CB,*i+n*	***i+0***	***i+1***	***i+2***	***i+3***	***i+4***	***i+5***	***i+6***	***i+7***	***i+8***
C	Constrains Budget	630,000	550,000	430,000	310,000	190,000	110,000	**70,000**	-	-
D	MA required	80,000	120,000	120,000	120,000	80,000	40,000	120,000	40,000	40,000
E	Allocated amount	80,000	120,000	120,000	120,000	80,000	40,000	-	-	-
F	Budget balance	550,000	430,000	310,000	190,000	110,000	70,000	-	-	-
G	Total allocated	80,000	200,000	320,000	440,000	520,000	560,000	-	-	-

Details of the conventional budget allocation table are described as the following

A = CB number. (12*, 8* and 30* means special condition CBs with high operating current and highly expect failure cost)

B = Allocation step (*i+n*) based on prioritized CB number.

C = Possible available amount of constrain budget to be allocated.

D = Maintenance budget required for CB,*i+n*

E = Allocated amount at CB,*i+n* (usually *E = D*)

F = Budget balance (*F = C-E*)

G = Total accumulate of allocated amount $(G = \sum_{i=1}^{n} CB, i, allc)$

A conventional budget allocation model in Table 20 represent how allocation takes place for MA required the amount of each critical CB at the sequence (CB,*i+n*). Allocation sequence starting from CB No-31 (Item -A) that correspond to CB,*i+0,* (Item-B). The budget amount is available for 630,000 Bahts (Item-C) which is sufficient to allocate for MA required of 80,000 Bahts (Item-D).

In case there is sufficient budget for allocation, the MA required amount will transfer to an allocated amount that equal to 80,000 Bahts (Item-E) in order to indicate actual maintenance amount has been allocated for this particular CB,*i+n*. For balance budget (Item-F), it calculates from the available budget (Item-C) deducted by the allocated amount (Item-E). Finally, the total amount will be accumulated by the allocated value. This sequence CB,*i+0*, is equal 80,000 Bahts (Item-G).

The routines will carry on until sequence no CB,*i+6*, which available balance budget is remaining 70,000 Bahts and it is not enough to allocate for MA required amount total 120,000 Bahts. Allocation process stops at CB,*i+5*, and available balance of 70,000 Bahts will not process to further allocate step due to the insufficient amount at step CB,*i+6*. These are the main reason that conventional allocation routine will not be fully utilized even balance is not zero and total CB allocation is limit to only six units.

2) Progressive budget allocation

Progressive budget allocation processing details are summarized in Table 21.

Table 21: Progressive budget allocation

Progressive budget allocation (Bahts)										
A	CB No	31	12*	18	13	8*	7	11	19	30*
B	CB,*i+n*	***i+0***	***i+1***	***i+2***	***i+3***	***i+4***	***i+5***	***i+6***	***i+7***	***i+8***
C	Constrains Budget	630,000	550,000	430,000	310,000	190,000	110,000	70,000	70,000	**30,000**
D	MA required	80,000	120,000	120,000	120,000	80,000	40,000	120,000	40,000	40,000
E	Allocated amount	80,000	120,000	120,000	120,000	80,000	40,000	-	40,000	-
F	Budget balance	550,000	430,000	310,000	190,000	110,000	70,000	70,000	30,000	-
G	Total allocated	80,000	200,000	320,000	440,000	520,000	560,000	560,000	600,000	-

Progressive budget allocation model has improved the weak point of the conventional method by using look forward to possible CB sequence (*i+n+1*, *i+n+2* ... *i+n+max*) until available budget become zero or cannot be allocated or less than minimum MA required. (for this study use 1% of CB value, 800,000 x 1% = 8,000 Bahts)

In the conventional process will stop at CB,*i+6*, due to 70,000 Bahts balance is insufficient for 120,000 Bahts that CB No-11 is required. However, if the allocation process has looked ahead by skipping CB,*i+6*, to CB,*i+7*, which required only 40,000 Bahts. This balance 70,000 Bahts is possible to allocate to CB,*i+7*. That gives the remaining balance of 30,000 Bahts. The allocation routine supposed to continue to look ahead step again but this time it will not proceed due to the special condition has indicated at CB No-30* at sequence CB,*i+8*. At this sequence, MA required is 40,000 Bahts which is higher than available 30,000 Bahts. Allocation process stops at this sequence with a total allocated of 7 CB.

The progressive allocation has effectively utilized the remaining balance of 70,000 Bahts in the conventional model. It is the most optimization method in case of the budget could not be adjusted.

3) Progressive budget allocation with suggestions

Progressive budget allocation with suggestions is the same routine as progressive budget allocation. The only difference is the extra amount of MA budget will be suggested in order to minimize this operation risk. Process flows and details summary are demonstrated in Figure 6 and Table 22. Information in Figure 6 shows a comparison of progressive amount (PGA) and progressive (CB,i+n) sequences, these are included strongly importance condition for operation current and expected failure costs criteria.

Table 22: Progressive budget allocation with suggestions details

Progressive budget allocation with suggestions (Bahts)										
A	CB No	31	12*	18	13	8*	7	11	19	30*
B	CB,*i+n*	***i+0***	***i+1***	***i+2***	***i+3***	***i+4***	***i+5***	***i+6***	***i+7***	***i+8***
C	Constrains Budget	630,000	550,000	430,000	310,000	190,000	110,000	70,000	70,000	30,000
D	MA required	80,000	120,000	120,000	120,000	80,000	40,000	120,000	40,000	40,000
E	Allocated amount	80,000	120,000	120,000	120,000	80,000	40,000	-	40,000	30,000
F	Budget balance	550,000	430,000	310,000	190,000	110,000	70,000	70,000	30,000	**(10,000)**
G	Total allocated	80,000	200,000	320,000	440,000	520,000	560,000	560,000	600,000	630,000

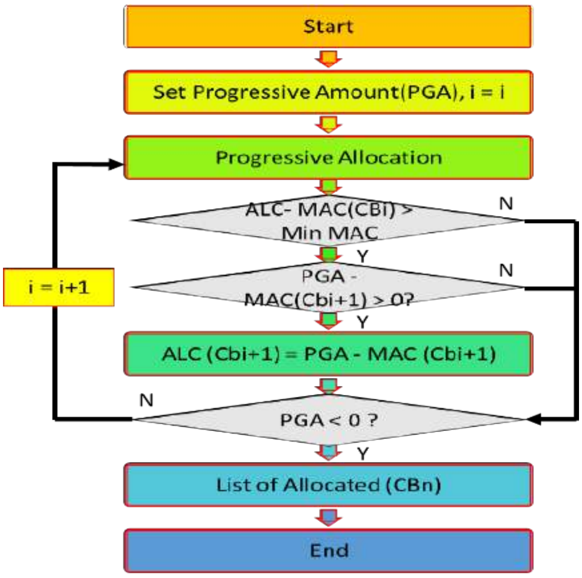

Figure 6: Progressive budget optimization with suggestion flows

This sequence CB,*i+8*, in Table 22, required 40,000 Bahts for maintenance but available balance is only 30,000 Bahts. Therefore, it needs an extra budget of 10,000 Bahts to make possible budget total 640,000 Bahts (630,000 +10,000) and accomplish one more extra critical CB for maintenance.

The constrains budget for 630,000 Bahts can be effectively utilized by using progressive budget allocation and the net balance, after allocated, was 30,000 Bahts. This process has been improved from the conventional allocation model which having the actual final balance of 70,000 Bahts. It means the balance from conventional allocation model is not effectively allocate. Therefore, the most effective allocation method is progressive budget allocation with suggestions that fully utilized all budget to critical CB and enhance the maintenance process with the suggestion for a small extra budget amendment.

In the conventional sequential allocation model No.1 that remaining balance is 70,000 Bahts for a maximum of six CBs. The balance from conventional allocation is still possible to make an allocation for further next CBs. This can be improved by progressive allocation model. In item No.2 the figure used progressive budget optimization (PBO) which can be utilized up to 7 units of CB and balance remains 30,000 Bahts that considered as the best allocation process. The allocation will not continue due to CB number 30 has special conditioned to be maintained. This model is applicable for constraining budget which cannot be amendment or increase. Finally, the last approach model in No.3, It serves the ultimate goal with fully utilized by progressive with suggestion model. It suggested for an additional amount of 10,000 Bahts and maximize up to 8 CBs while skipping CB-11 due to budget is not sufficient to make the allocation.

This summary can indicate that progressive with suggestion model is the most effective allocation process for the budget optimization procedure.

4. PRIORITIZATION AND OPTIMAL BUDGET MODEL SIMULATION RESULTS

There is a total of five reports of simulation results in graphical format. The output illustrates that prioritization and optimal budget model can achieve the objectives as detailed in the following.

4.1 REPORT#1: CIRCUIT BREAKER HEALTH INDICES REPORT

This circuit breaker health indices report indicates the accumulated critical weight based on their criticality condition of each CBs using AHP model. There is a total of 32 breakers. Figure 7 shows the higher weight for CB number 31,12,18,13,8 and so forth. The higher critical value means that CB has a more serious condition. Report 1 is illustrated in Figure 7.

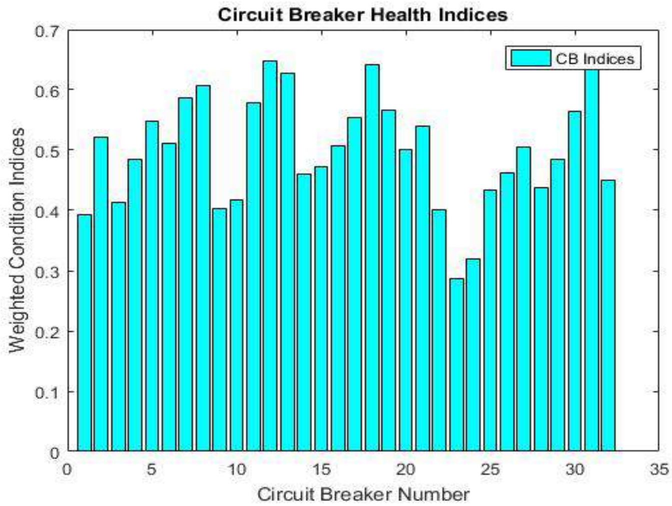

Figure 7: Circuit breaker health indices.

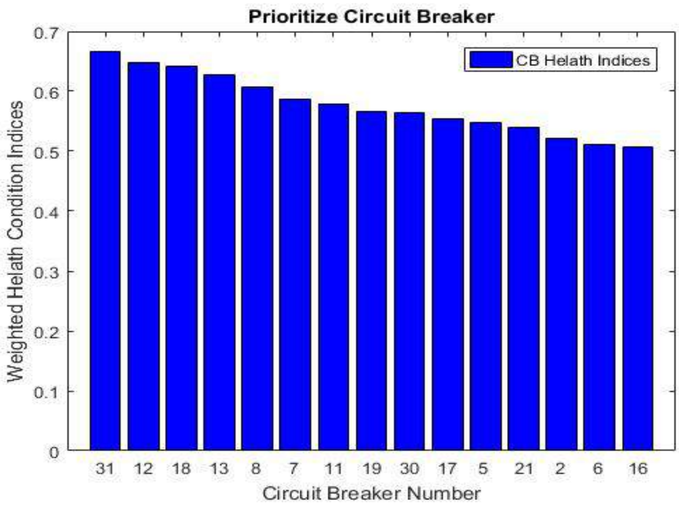

Figure 8: Prioritize circuit breaker ranking.

4.2 REPORT#2 PRIORITIZE OF CIRCUIT BREAKER

This prioritized circuit breaker is classified based on their health indices. It indicates the accumulated critical weight based on their criticality condition of each CBs in sorting sequence. There is a total of 32 breakers. Figure 8 shows the higher weight for CB number 31,12,18,13,8 and so forth. The higher critical value means the higher priority for that particular CB that should be maintained first. Report-2 is illustrated in Figure 8.

4.3 REPORT#3: MAINTENANCE BUDGET REQUIRED FOR EACH CB

The prioritized circuit breaker is classified based on their health indices including budget required in according to their characteristics. It indicates maintenance amount based on their criticality condition of each CBs with sorting sequence. Figure 9 shows, the higher weight for CB number 31 may need maintenance budget less than CB number 12 due to their characteristics. For example, SF6 may need more budget than air-dielectric.

In this report, there are additional important criteria to be considered in case of a progressive process to skip using *(i+n)* sequence or need to be maintained by extra budget required. There are two additional criteria to the analysis. The first one is operating current and second factor is failure rate which impacts to service quality.

Figure 9 illustrates CB number 12,8,30 and 21 with additional two factors for consideration when progressive sequence condition has performed.

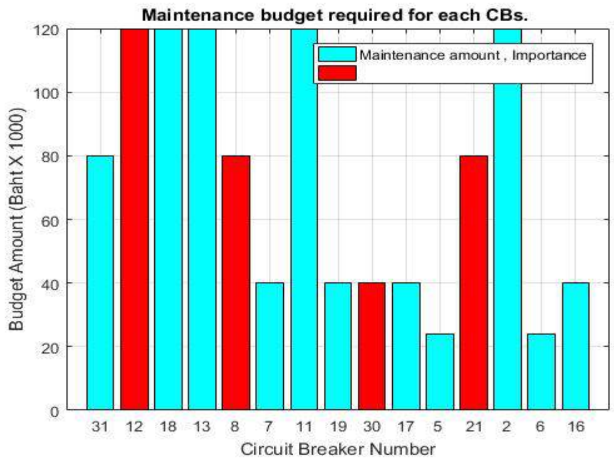

Figure 9: Maintenance budget required for circuit breaker.

This report shows the maintenance amount required to maintain each circuit breaker according to their health conditions including quality service criteria.

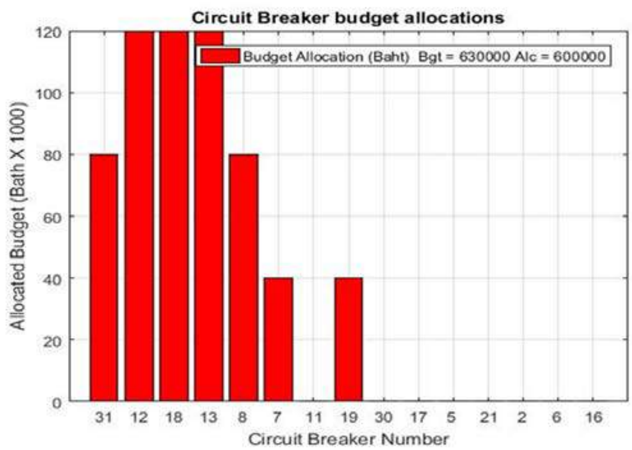

Figure 10: Optimal maintenance budget allocations based on the budget constraint.

4.4 REPORT 4: CIRCUIT BREAKER BUDGET ALLOCATIONS

The allocation process will need constraint budget to be allocated for each prioritized circuit breaker based on their health indices including budget required in according to their characteristics. In Figure 10, shows the higher weight for CB number 31 may need maintenance budget res than CB number 12 due to their certain character. For example, SF6 may need more budget than air-dielectric.

Total constraint budget of 630,000 has allocated to CB number 31,12,18,13,8,7 and 19. The progressive has performed to skip the allocation amount to CB number 11 according to available balance is not sufficient. By skipping CB number 11, the remaining budget is possible to allocate to CB number 19 while the last balance is 30,000 Bahts which will not be able to allocate to any CB due to CB number 30 has special condition (CRI,4 + CRI,7 = high value) which should not skip.

These are the standard process of progressive budget allocation that optimizes the constrained budget for most possible conditions. This method is suitable for a fixed budget that could not be adjusted according to the maintenance budget policy.

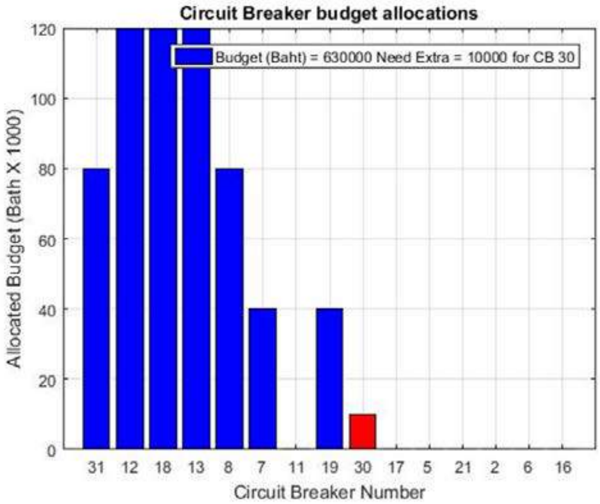

Figure 11: Optimal maintenance budget allocation with progressive suggestions.

4.5 REPORT#5: CIRCUIT BREAKER BUDGET ALLOCATION WITH SUGGESTIONS

This process will need extra additional for constraint budget for allocation to each prioritized CB based on their health indices and budget required according to their characteristics. In Figure 11, shows the higher weight for CB number 31 may need maintenance budget less than CB number 12 due to their certain character. For example, SF6 may need more budget than air-blast. Total constraint budget of 630,000 has allocated to CB number 31,12,18,13,8,7 and 19. The progressive has performed to skip the allocation amount to CB number 11 according to available balance is not appropriate. By skipping CB number 11, the remaining budget is possible to allocate to CB number 19 while the last balance is 30,000 Bahts which will not be able to allocate to the next ahead (CB number 17, 5) due to CB number 30 has special conditioned to be maintained. There are additional importance criteria for this condition to be considered in case of a progressive process to skip using *(i+n)*, sequence or need to be maintained by extra budget required. There are two additional criteria to analyze, the first one is operating current and second factor is failure rate which impacts to service quality. This is the reason that progressive process will not skip CB number 30. These are the standard process of progressive budget allocation with a suggestion that can optimize the constrained budget for most possible conditions.

5. DISCUSSION

The simulation output comparison for budget details allocation model from Conventional, progressive and progressive with suggestion model can be described by Table 22:

Table 22: Allocation model summary.

Allocation Model	Budget Bahts	Allocated Bahts	Balance Bahts	Suggests Bahts	Total CB Unit
1. Conventional allocation	630,000	560,000	70,000	-	6
2. Progressive allocation	630,000	600,000	30,000	-	7
3. Progressive with suggestion	630,000	630,000	-	10,000	8

In the allocations model summary of Table 22. There are three allocations models, starts with conventional, progressive and progressive with a suggestion that can be summarized as follows:

1) Conventional allocation

Conventional allocation method No.1 is a sequential allocation model by incremental step by step while deducts the allows budget amount until it is not possible or balance is not sufficient. This model can allocate the budget of 530,000 Bahts that remaining balance is 70,000 Bahts for a maximum of 6 CBs. The balance from conventional allocation is still possible to make an allocation for further next few steps of CB. This balance can be improved by progressive allocation model.

2) Progressive allocation

In item No.2 the figure used progressive budget optimization (PBO) which can be utilized up to 7 unit of CB and balance remains 30,000 Bahts that considered as the best allocation process. This model is applicable for constraining budget which cannot be amendment or increase.

3) Progressive allocation with suggestions

This is the most optimized approach model in No.3. It has the ultimate method for full utilization by progressive with suggestion model which including a suggestion for an additional amount of 10,000 Bahts and maximize to 8 CBs while skipping CB-11 due to budget is not appropriate to make an allocation. The additional value is considered as 1.59% of the budget amendment. This summary can indicate that progressive with suggestion model is the most effective allocation process for budget optimization procedure and can apply for what if scenario to exercise the budget in accordance with policy. Each scenario can have exactly answering details, for example.

a. How many prioritized CB can be maintained using the allowed budget?
b. What would be an appropriate budget for CB maintenance this year?
c. If we reduce the budget by 5%, what is maximum CB can be maintained?

6. CONCLUSION

This paper has achieved the proposed model for comprehensive qualitative-quantitative prioritizing and PBO process. It can determine the appropriate CB for prioritization based on their condition using AHP in CBM. The constrained budget is also optimized in accordance with management policy.

The evaluation is performed by each CB's indices condition and corresponds to the allocation amount based on criticality and impact of severity. With this new approach, PBO is interactive decision-aid tools, capable of providing effective CB maintenance management and planning and can answers the "what-if" questions in short periods of time. Also, the PBO utilizes the deterministic what should be the best scenario in justification for CB annual budget planning that shuts the gap between operational requirements and financial management policy. These main achievement features and benefits associated with this proposed scheme are summarized as follows.

1) Determine critical and prioritized CB. It can effectively evaluate and determine the high prioritized of CB to be maintained based on CBM in reliability service, quality service, business risk and maintenance costs.
2) Budget optimization according to budget constraints. It provides the optimized of constraints amount for allocation to individual prioritized CB.
3) Maintenance operation and planning. This approached model will increase the confidentiality of maintenance operation resources allocations of service and support in a short period of time.
4) Budget justification and evident support between maintenance operation and financial management. This will reduce the complexity of CBs determination or decision-making for CBs maintenance strategic planning and annual budgeting.
5) CB condition data preparations for real-time condition monitoring.
6) Provides pro-active for periodic review and revision.
7) A budget optimization model for application integrates with other related subjects. This progressive budget optimization model can be easily combined with the other sectors or budget optimization techniques and solving via different techniques.

This CB budget optimization model has satisfied the objectives, however, there are possibilities for the following further study:

a) Make alternative disciplined approach to maintenance planning strategy.
b) Development of additional criteria for real-time sensor monitoring technologies.
c) Improvement of maintenance collection and analysis techniques.
d) Budget optimization with the graphic user interface (GUI) maintenance tool.
e) Integration with other related systems into the program interface structure.

7. DATA AVAILABILITY STATEMENT

The used or generated data and the result of this study are available upon request to the corresponding author.

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