Asset Management for Power Transformer in High Voltage Substation

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ABSTRACT

In this paper, an innovative asset management in inventory control of power transformer in high voltage substation is proposed. Using Pareto analysis, the components of power transformer are classified into ABC Classes. Class A means the few most expensive ones that need special care. Class B means ordinary ones that need standard care. Class C means the large number of cheap items that need little care. The inventory management strategies as statistical distribution methods, economic ordering policy, and two-bin policy are initiatively applied to the transformer components in the ABC Classes. Finally, the optimum number of spare parts, the optimum ordering quantity, the suitable time for reordering, and the saving inventory cost are determined in order to minimize the total inventory cost. The power transformer fleet in Thailand is presented as example of inventory control of transmission asset.

Keywords: Asset Management, Inventory Control, Pareto Diagram, Economic Ordering Quantity, Poisson Distribution, Normal Distribution, Two-bin Policy

1. INTRODUCTION

High voltage equipment such as power transformer, circuit breaker, disconnecting switch, surge arrester, etc. are important components in power system. Especially, power transformer is gradually deteriorated every day such as shortened lifetime due to oxidation, moisture and temperature, acidity and contamination of insulating oil, seal and gasket deterioration. If the maintenance cannot detect and fix the problem in time, the catastrophic failure will occur, which leads to tremendous damage and outage cost to electric utility [1]. Therefore, high voltage equipment must be maintained its satisfactory operating condition by applying an effective maintenance strategy. Maintenance, availability and reliability are closely related so that a level of maintenance should be specified to ensure an acceptable level of transformer reliability. Maintenance strategies are mainly classified into corrective, preventive, condition-based and reliability-centered.

The corrective maintenance for replacement or repair is needed when a failure occurred. It is mainly used in systems with lower voltages. Advantages of the corrective maintenance are low cost and manpower saving, whereas one of disadvantages is that it might be too late to be repaired if failures are not detected early [2]. The preventive maintenance is routine and basic maintenance in fixed intervals for inspections and maintenance. Advantages are lifecycle increasing and fault inception detecting. However, disadvantages are that if some parts of the equipment might be timely maintained, damages might occur before the maintenance. If the parts are too early maintained, it will be expensive due to such maintenance and unnecessary shutdowns [3]. The condition-based maintenance is followed by its condition or the condition is taken into account. All major parameters such as diagnostic methods are considered in order to determine the condition with maximized accuracy. Advantages are that the maintenance is done when needed; and costs as well as manpower are saved. Disadvantages are that experienced people and suitable data are required [4]. The reliability-centered maintenance (RCM) considers the condition as well as the importance of equipment. It evaluates priority for maintenance actions and ranks the replacement and refurbishment activities. If the economical consequences from different actions are concerned, the RCM is extended to risk-based maintenance [5]. However, even if the RCM is cost optimizing method based on risk and unnecessary shutdown, disadvantages are that it is a complex model and lots of data are required. The most appropriate maintenance strategy to maintain the equipment for the electric utilities is preventive maintenance because of simple, noncomplex, and minimum data required method. However, its disadvantages in spare parts and costs of inventory should be mitigated.

In this paper, the effective inventory management strategy for high voltage equipment in a Thai utility is proposed. The methods to determine the optimum number of spare parts, the optimum ordering quantity, the suitable time for reordering, and the saving

Manuscript received on June 6, 2012 ; revised on November 26, 2012.
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inventory cost are suggested in order to minimize the total inventory cost of high voltage equipment. Since the major components of power transformer as shown in Fig. 1 are usually expensive and have low turnover demand of inventory. Thus, a number of such components stored in stock are limited by capital investment cost. Power transformer components are classified in ABC Classes using Pareto analysis. For Class A, bushing and arrester are proposed. The failure records of power transformer are analyzed by statistical techniques as Normal and Poisson distributions in order to determine failure rate and replacement rate. The optimum number of spare parts can be determined according to the required stock reliability. For Class B, the insulating oil is given as an example. The amount and time for reordering insulating oil is proposed. For Class C, the spare parts of cheap items of power transformer as nuts, bolts and gaskets are presented by using two-bin policy. This proposed strategy performs the revolution to the new era of effective preventive maintenance in order to optimally control the spare parts of HV equipment by analyzing the statistical failure records and inventory costs. Consequently, the overall cost of maintenance can be reduced.

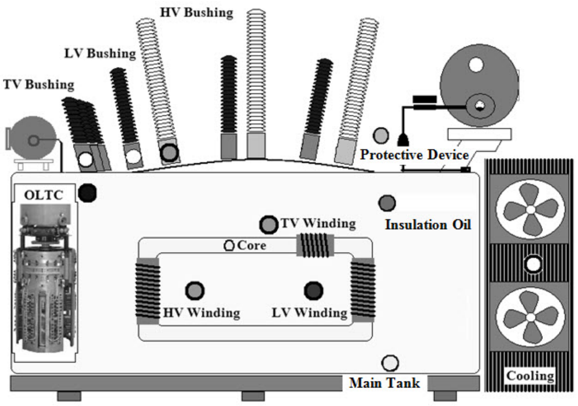

Fig.1: *Power Transformer's Components.*

2. REVIEW OF SPARE PART MANAGEMENT

The availability of spare parts is a significant subject of effective maintenance strategy because it can reduce downtime or supply interruption due to equipment failure. A large amount of spare parts stored in the stock can provide the high reliability of equipment utilization and reduction of downtime and repair time, but it is not cost-effective method due to high initial investment cost. Therefore, the optimum number of spare parts in stock must be determined in order to minimize the cost of inventory. Several methods were applied for the effective inventory management. In [6], aircraft spare parts were performed by using an organizational perspective on inventory control to ensure maximum availability of aircraft for operational use. However, the proposed method was appropriate only for small inventory system.

In [7], three probabilistic models as Poisson distribution, Markov process, and chronological Monte Carlo simulation were compared to assess the reliability and inventory of spare transformers in distribution substations. The reliability of the system was assessed in the aspect of when inventory cannot be timely replenished by using Poisson method. However, the Markov and chronological Monte Carlo models were proposed to extend the capability of reliability assessment. Only spare parts for distribution transformers were determined.

In [8], the Homogeneous Poisson Process (HPP) method was applied as a mathematic model to the failure data of distribution transformers in order to predict proper number of spare distribution transformers. This method did not require a complete homogeneity of the failure data; but it was based on the chi-square goodness of fit test.

In [9], the probabilistic approach was proposed to determine the number and timing of spare transformers in medium, voltage substation. The aging failure of transformers, overall reliability, probabilistic damage cost, and capital cost of spare parts were analyzed. However, only non-repairable failure components were considered in the inventory. In addition, the Poisson probability distribution was mentioned to determine the optimal number of transformer's spare part for distribution transformer [10]. The number of spare requirements for a system depended on the reliability level demanded from the system. The economic model was involved to minimize the total system cost.

In [11], the economic order quantity was proposed for the practical inventory control. The stock on hand, net stock, optimum spare part, order size, and order point were analyzed. This method was simple and applied suitably to the complex task with various control variables. Furthermore, the inventory cost optimization was investigated.

Therefore, this paper discusses two probabilistic distribution methods, which are Poisson and Normal distributions, to determine the number of spare parts in Class A of high voltage power transformer because these two techniques are suitable for the repairable components with sufficiently available failure data. Regarding to aforementioned advantages of economic order quantity, this method is proposed for Class B spare parts of power transformer. In Class C, due to inexpensive items, a basic inventory control method, so-called the two-bin policy is introduced in this paper. With this effective inventory management, electric utility or company can not only reduce the direct cost of inventory, but also can significantly reduce hidden capital costs such as supply interruption and increase reliability of electricity supply.

3. SPARE PARTS CLASSIFICATION

Pareto diagram [12-13] is a general method to classify spare parts or item listed in the inventory into A, B, C Classes according to the cost of items and amount of usage. Thus, spare parts of high voltage equipment in power system can be classified by using the aforementioned Pareto diagram. Usually in inventory system, the higher cost items account for a smaller portion of a total number of items. The analysis starts from; firstly the cost of each item is calculated as a percentage of the total cost of inventory items. Then, the items, which are in descending order of the percentage of the item's cost to the total inventory cost, are ranked starting from the items that contribute the highest cost. Finally, the graph is plotted with percentage of item used on the X axis and percentage of its cost on the Y axis as shown in Fig. 2.

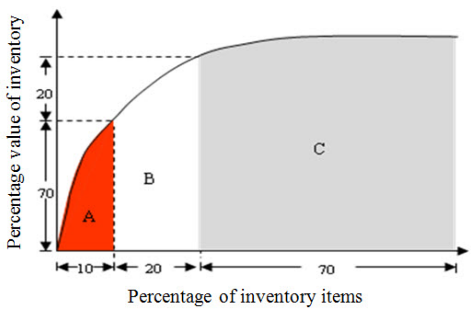

Fig.2: *ABC Class Analysis in Pareto Diagram.*

Using Pareto analysis in Fig. 2, the components of high voltage equipment can be classified into ABC Classes.

- Class A items are account for 70% to 80% of the total inventory cost but about 20% of total inventory items. This class needs a high capital investment and requires a close control. Then it will be ordered based on calculations of the most economic order quantities. Due to high cost of these items, a minimum safety stock is maintained.

- Class B items are account for 20% to 30% of the total cost but about 20% to 30% of total items. Compared to Class A, the larger safety stocks may be maintained and do not need a special control.

- Class C items are account for 20% of the total cost but about 70% to 80% of total items.

Fig. 2 shows the relationship between yearly percentage costs of inventory versus yearly percentage of inventory items of ABC Classes. Thus, the cost of item usage in each class can be calculated from the cumulative number of item used multiply to the price per item.

After the items are classified into three different ABC Classes, different inventory policy has been applied for each class. For Class A, it needs a close control and number of spare parts is based on minimum safety stock with acceptable stock availability, so that the statistical distribution techniques are applied to this class. Economic order quantity is usually employed to Class B item to minimize inventory cost, while Class C item is managed by a simple two-bin policy. The procedure is summarized in Fig. 3.

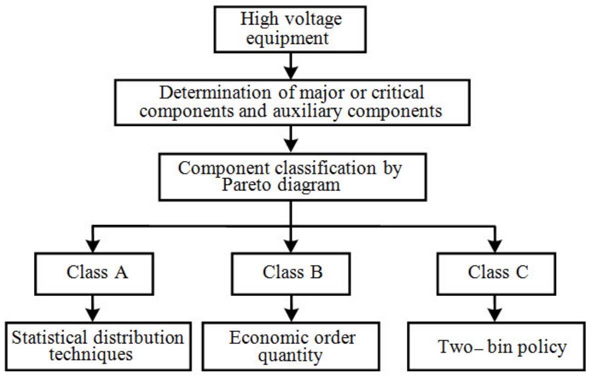

Fig.3: *Spare Part Classification and Inventory Control.*

4. SPARE PARTS CALCULATION

4.1 Class A Item of Power Transformer

Since items in Class A are the most expensive but used only few, e.g. bushing, surge arrester, on-load tap changer of the power transformer; the amount of spare part in this class is also accounted only few items. To find the optimum amount of spare parts, the statistical distribution techniques are applied. The failure records are analyzed in order to determine failure rate or replacement rate of each component. Subsequently, the known failure or replacement rate is calculated by using statistical distribution techniques as the Normal and Poisson distribution techniques to determine the optimum number of spare parts.

A. Normal Distribution Technique [14]

Normal distribution technique is a highly accurate technique, especially when the number of recorded failure data is sufficient with adequate information suitable for the analysis and the first energization or startup date or manufacturing date must be known. First, the number of service years is calculated from the sum of operating time that every piece of component is in service or until failed date of prematurely failed components. Therefore, the service year time is a time span from the first startup date until present for healthy components in service. Then the failure rate is calculated; and finally, the optimum stock for smooth operation within the equipment lifetime can be determined from:

$$N = M(\lambda \cdot T + \sqrt{\lambda \cdot T \cdot Z}) \quad (1)$$

$$\lambda = \text{failure rate} = \frac{\text{number of failures}}{\text{number of service years}} \quad (2)$$

where: M = number of the items used in the system, T = lifetime of considered item. Z can be obtained from the pre-calculated standardized normal tables. Thus from Table in [15], if availability in stock is required as 99% of service level, then Z is equal to 2.33.

B. Poisson Distribution Technique [16]

This technique is an effective tool to analyze a few recorded failure data within a specific time intervals (T_i). The Mean Time between Failure ($MTBF$) or Mean Time to Replacement ($MTTR$) can be calculated from:

$$MTTR(\mu) = \frac{MxT_i}{N_f} \quad (3)$$

where M is number of the items used in the system. T_i is time intervals for replacement rate consideration. It is usually counted from present to a specific time in the past in order to count the number of failure occurring with each component. N_f is number of failures occurring within time interval T_i. The replacement rate (λ) can be written as:

$$\lambda = \frac{1}{\mu} \quad (4)$$

and the expected number of demand (A) is

$$A = M\lambda T \quad (5)$$

when T is lead time of stock ordering. The probability of item (P) will be kept in time is

$$P = \frac{A^I \times e^{-A}}{I!} \times 100 \quad (6)$$

where I is number of the items kept in the stock. Finally, the percentage of stock reliability or availability of items in the stock within the time interval is

$$\%R_I = \sum_{i=0}^{I} P_i \quad (7)$$

The statistical method proposed in this paper can also be applied to other components of high voltage equipment.

4.2 Class B Item of Power Transformer

B items are ordinary ones that need standard care. For Class B item, three categories as economic order quantity, safety stock, and reorder level based on demand rate can be applied for inventory control of this class.

Economic Order Quantity: The main objective of economic order quantity [17-18] is to minimize cost of operating inventory system and overall cost. The relevant costs considered to be significant are cost of item, procurement costs and carrying cost. These costs are related as the following relationship.

$$TC = CD + S\frac{D}{Q} + I_c\frac{Q}{2} \quad (8)$$

where TC is total annual cost, C is item cost, D is annual demand, S is ordering cost, Q is quantity ordered, and I_c is inventory carrying cost.

By taking partial derivatives of TC with respect to Q in (9), the order quantity Q can be calculated in (10).

$$\frac{\partial TC}{\partial Q} = 0 + (-SDQ^{-2}) + \frac{I_c}{2} \quad (9)$$

$$Q = \sqrt{\frac{2DS}{I_c}} \quad (10)$$

For example, an item has following data. The annual demand (D) is 200 units, Cost/item is \$10, Cost of placing order (S) is \$15 and Annual carrying charges is 15% of the item cost. When all items are substituted into (10), thus Q is approximately equal to 64 units. By applying this category, the part should be ordered as 64 units.

Safety Stock: Safety stock is established to prevent stock outage during lead time period. It is usually applied when the lead time is fluctuated [19]. The safety stock can be determined as:

$$\text{Safety stock} = R - \mu = \sigma Z \quad (11)$$

where R is reorder level, μ is expected demand during lead time, σ is standard deviation, and Z can be obtained from standardized normal table.

For example to compute safety stock for HV bushing, the lead-time demand of a certain type of HV bushing is normally with a mean (μ) of 150 units and a standard deviation (σ) of 5 units. The manager wants to pursue a policy whereby the HV bushing is not available only 1% of the time when demanded. Thus from Table in [14], for 99% service level, Z can be obtained from standardized normal tables. Thus Z is equal to 2.33. So, safety stock ($R - \mu$) is equal to $11.65 \approx 12$ units.

Reorder Level: The reorder level of inventory control system shown in Fig. 4 refers to amount of item in inventory, at which level order should be triggered [15].

It is calculated by the known demand during lead time to make sure that the new order quantity will be received before the item in inventory reaches 0. The reorder level can be calculated as:

$$R = \mu + \sigma Z \quad (12)$$

From the previous example, the replenishment order should be placed when unit is $R = 150 + 12 = 162$ units.

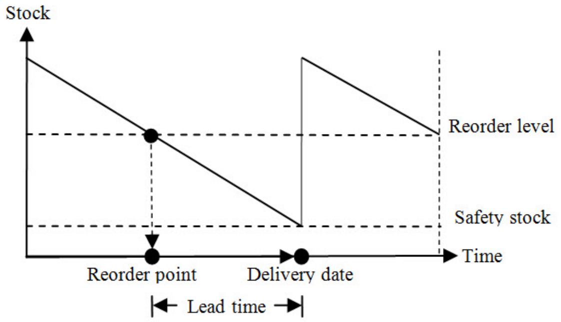

Fig.4: *Reorder Level Management.*

4.3 Class C Item of Power Transformer

C items are the large number of cheap items that need little care. Two-bin policy [14] is applied for this class as presented in Fig. 5.

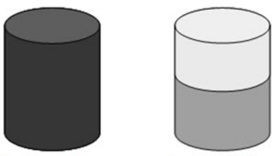

Fig.5: *Two-bin Inventory Control.*

Items are kept in the maintenance shop in two-bin of equal sizes. Items are withdrawn from the first bin. When its contents are exhausted, it is time to reorder. The second bin size is sufficient to satisfy expected demand during the lead time period and a safety stock in order to avoid a possible stock outage.

5. RESULT AND ANALYSIS

The power transformers in the Thai power system are presented as examples. Power transformer's components are classified into ABC Classes according to Pareto diagram as given in Table 1. The components of power transformer in Class A are busing, arrester and on-load tap changer, etc. The Class B item of power transformer is insulating oil. The item in Class C has the cheapest price and needs a minimal control, e.g. seal, gasket, bolt and nut. In this paper, the calculation for the optimum spare part number of items in Classes A, B and C are presented.

5.1 Class A Item of Power Transformer

A. Transformer Bushing

The 115 kV bushings will be investigated as an example for spare part management for a fleet of power transformers in transmission network. The data of 120 bushings from 40 power transformers rating 115/22 kV, 25 MVA show that the total service years is equal to 1,890 unit-years. The design lifetime of bushing is usually specified as 25 years. From

Table 1: *Power Transformer Component Classification.*

Class	Power Transformer's Components
A	1. Active parts: core, winding (HV/LV/TV) 2. Bushing (HV/LV/TV) 3. Cooling system: fan, pump 4. Protective device: pressure relief, Buchholz relay, OLTC pressure relief, OLTC protective relay, OLTC pressure relay, OLTC oil flow relay, oil temperature, gas detector, sudden pressure relay, winding temperature, percentage differential relay, over current relay 5. OLTC: contact of diverter switch, contact of selector switch 6. Surge arrester (HV/LV/TV) 7. Tank: diaphragm/rubber bag
B	Insulating oil in main tank and in OLTC
C	Others as nuts, bolts, o-rings, gaskets, etc.

the recorded failure, there are 5 failure records within 10 years time interval. If the need for availability of items in stock is 99% of service level, the number of 115 kV bushing, which should be kept in the stock, can be calculated as follows.

*1)*Normal distribution technique: Failure rate is equal to 5/1,890 = 0.002646 times per year. If the required availability is 99%; then from the standardized normal table, Z = 2.33. Thus, the number of bushings in the stock is equal to

$$N=\frac{120\times 0.002646\times 25+\sqrt{0.002646\times 25\times 2.33}}{25}=2.2$$

or 3 units per year for the total 40 units of power transformers.

*2)*Poisson distribution technique: For the same group of transformers, Mean Time to Replacement ($MTTR$) for the specific time 10 years period is calculated as

$$MTTR(m)=\frac{M\times T_i}{N_f}=\frac{120\times 10}{5}=240$$

Thus, the replacement rate is $\lambda=\frac{1}{m}=0.00417$.

Considering the lead time (T) for ordering bushing is 1 year, the expected number of demand for bushing is equal to $A=M\lambda T=120\times 0.00417\times 1=0.5$. Thus, the probability of having 0.5 bushing available in the stock in one year time interval can be calculated from (6) and reliability from (7). The results are given in Table 2.

From the probability and reliability of bushing in stock, it is seen that the 115 kV bushing should be kept in stock 3 units per year in order to obtain the 99% reliability of stock. This number is similar to the result obtained from the Normal distribution technique.

B. Surge Arrester

With the same method, the 115 kV surge arrester will be further investigated. The data from a similar

Table 2: *Probability and Reliability of Bushing Stock.*

Stock Level, I	P_i	Reliability, $\%R_I$
0	60.65	60.65
1	30.33	90.98
2	7.58	98.56
3	1.26	99.82
4	0.16	99.98
5	0.02	100.00

group of 40 power transformers rating 115/22 kV, 25 MVA shows that the total service year of 120 arresters is equal to 2,350 unit-years. From the recorded failure, there are only 2 failure records occurring within 10 years time interval. The design lifetime of arrester is also specified as 25 years. If the need for availability of items in stock is 99% of service level, the number of 115 kV arresters, which should be kept in the stock, can be calculated as follows

1) Normal distribution technique: Failure rate is equal to 2/2,350 = 0.000851 times per year. If the required availability is 99%; then from the standardized normal table, $Z = 2.33$. Thus, the number of arresters is

$$N = \frac{120 \times 0.000851 \times 25 + \sqrt{0.000851 \times 25 \times 2.33}}{25} = 1.2$$

or 2 units per year for the total 40 units of power transformers.

*2)*Poisson distribution technique: For the same group of transformers, the Mean Time to Replacement (MTTR) is calculated as:

$$MTTR(m) = \frac{M \times T_i}{N_f} = \frac{120 \times 10}{2} = 600$$

Thus, the replacement rate is $\lambda = \frac{1}{m} = 0.00167$.

Considering the lead time (T) for ordering arrester is also 1 year, the expected number of demand for arrester is equal to $A = M\lambda T = 120 \times 0.00167 \times 1 = 0.2$. Thus, the probability of having 0.2 arrester available in the stock in one year time interval can be calculated from (6) and reliability from (7). The results are given in Table 3. From the probability and reliability of arrester in stock, it is seen that two units of 115 kV arresters should be kept in stock per year in order to obtain the 99% reliability of stock. This number agrees with the result obtained from the Normal distribution technique.

Table 4 and Table 5 summarize the number of bushings and arresters per year for various power transformer ratings in the system. For instance by using both Normal and Poisson distribution techniques, the number of 500 kV bushing for 333 MVA power transformers is 2, while that of 115 bushing for 100

Table 3: *Probability and Reliability of Arrester Available in the Stock.*

Stock Level, I	P_i	Reliability, $\%R_I$
0	81.87	81.87
1	16.37	98.25
2	1.63	99.88
3	0.11	99.99
4	0.00545	99.999

Table 4: *Number of Bushing per Year for Various Transformer Rating.*

Rating data / data used in the analysis	Bushing of Power Transformer				
	500 kV 333 MVA	230 kV 200 MVA	230 kV 300 MVA	230 kV 333 MVA	115 kV 100 MVA
Number of equipments	63	429	105	63	30
Results from Normal Distribution Technique					
Number of failures	1	4	1	2	2
Service years	372	7,260	1,143	372	708
Failure rate	0.0027	0.0005	0.0009	0.0054	0.0028
Number of spare parts	2	4	2	2	1
Results from Poisson Distribution Technique					
Number of failures	1	2	1	2	1
Service years	294	2,097	510	294	150
Failure rate	0.0016	0.0005	0.0019	0.0032	0.0067
Number of spare parts	2	3	2	3	1

Table 5: *Number of 115 kV Arrester Spare Parts for 50 MVA Transformer.*

Rating Data/Data Used in the Analysis	115 kV Surge Arrester for 50 MVA Transformer
Number of equipments	642
Results from Normal Distribution Technique	
Number of failures	5
Service years	9,144
Failure rate	0.000547
Number of spare parts per year	5
Results from Poisson Distribution Technique	
Number of failures	3
Service years	3,183
Failure rate	0.000943
Number of spare parts per year	7

MVA power transformers is 1. The number of 115 kV arresters for 50 MVA power transformers is 5 and 7 by using Normal and Poisson distributions, respectively.

5.2 Class B Item of Power Transformer

For Class B, the optimum number of ordering insulating oil is presented. The economic order quantity is applied to determine the optimum ordering quantity of insulating oil. By using the data in Table 6, substituting in (10), the optimum order quantity of insulating oil is 175 tanks/times. Note that 1 tank = 200 liters.

Table 6: *Insulating Oil Ordering Information.*

Items	Data
Annual demand (D)	540 tanks/year
Cost of item (C)	13,402 Baht/tank
Cost of placing order (S)	60,000 Baht/time
Annual carrying cost (I_c)	2,116 Baht/tank
Lead time	90 days
Demand during lead time (μ)	133 tanks
Standard deviation (σ)	5 tanks/90days
Probability of unit not available	1%

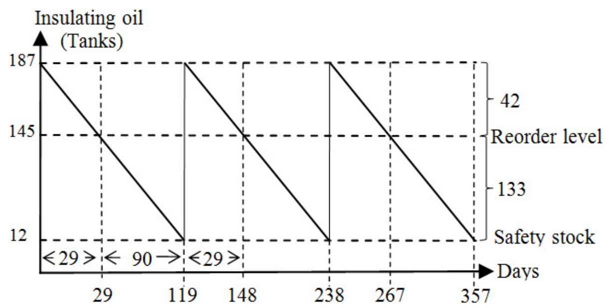

Fig.6: *Ordering Schedule of Insulating Oil.*

For the 99 percents of confidence which is surely that insulating oils are available when demand occurred, Z can be obtained from standardized normal tables as 2.33. By substituting data in (11), σZ = 12 tanks. So, the safety stock for insulating oil is 12 tanks. It can make sure that 99 percent during lead time, stock is not outage when the demand occurred. Then, to determine the appropriate time for placing an order, substituting safety stock and mean demand during lead time into (12), R is 133+12 which is equal to 145 tanks. It means that when insulating oils in stock decrease to 145 tanks, the order of 175 tanks should be placed. If daily demand is constant, it will take around 4 months to place an order again. Therefore, it is around 3 times per year for ordering insulating oil, as shown in Fig. 6.

The total annual cost is calculated by using the results from economic order quantity method. By substituting the calculated data into (8), the total annual cost is accounted around 7,602,230 THB/year. However, if placing an order once a year, the total annual cost will increase to 7,868,400 THB/year. Thus, by following the economic order quantity, the utility can save the budget for ordering insulating oil around 266,170 THB/year.

5.3 Class C Item of Power Transformer

The components in Class C for transformer are usually small or low value items such as nuts, bolts, o-rings, gaskets, etc. Therefore, the items are ordered as a large quantity but low budget. As shown in Fig. 5, when the first bin of such components is used up, an order is made out for replenishment. The second bin contains enough quantity of the item to last until the ordered quantity arrives.

6. APPLICATION TO HV EQUIPMENT IN POWER SUBSTATION

The proposed inventory management strategy in this paper can be further applied to other high voltage equipment in power system. Example on power circuit breaker is explained. The components of power circuit breakers can be similarly classified into ABC Classes based on Pareto diagram and according to the IEEE standard [20], as written in Table 7.

Table 7: *HV Circuit Breaker Component Classification.*

Class	HV Circuit Breaker's Components
A	1. High-voltage components: interrupter, auxiliary interrupter, insulation to ground 2. Mechanical parts: energy storage, control elements, actuator 3. Operating mechanisms: compressors, pump, mechanical transmission
B	1. Electrical control and auxiliary circuits: trip and close circuits, auxiliary switches, contactors, etc. 2. Insulating medium such as oil, SF_6
C	Others, nuts, bolts, o-rings, gaskets, etc.

The high voltage components of power circuit breaker such as interrupter, auxiliary interrupter are categorized into Class A because their high capital investment and close control are required. The insulating medium such as oil and SF_6 is categorized into Class B that needs standard care, whereas inexpensive items such as nuts, bolts, and o-rings are categorized into Class C that needs little care.

Similar to the strategies applied to power transformer components, to optimize the total inventory cost of power circuit breaker, the statistical distribution techniques with the Normal and Poisson distributions are applied to Class A items of power circuit breakers. The economic order quantity and the two-bin policy are applied to Class B and Class C, respectively. The calculation and analysis can be performed accordingly.

7. CONCLUSION

This paper presents the cost-effective inventory management strategy for high voltage equipment in power system. The spare parts of power transformer are categorized into ABC Classes on a basis of the Pareto analysis. Class A items are spare parts, which are ordered by considering failure rate of components and using the statistical distribution techniques that are the Normal and Poisson distributions. Economic Order Quantity model is applied to estimate the optimum number of spare parts in Class B, whereas two-bin policy is handled to place an order of spare parts in Class C.

The 115 kV bushings and 115 kV arresters of power transformers rating 115/22 kV 25 MVA are investigated thoroughly for spare part management as Class A. The result shows that Normal distribution technique provides the optimum number of spare parts similar to Poisson distribution technique for both bushings and arresters. Besides, the optimum number of bushings and arresters for various power transformer ratings in the system are determined. Only a few numbers of bushings and arresters should be kept in the stock each year. Insulating oil of power transformer is examined as Class B. The result indicates that the order of 175 tanks should be placed, while the safety stock and the reorder level are 12 tanks and 145 tanks, respectively. The cheapest price items such as nuts, bolts, o-rings and gaskets are mentioned for inventory management as Class C.

This innovative inventory management is now implemented in an electricity utility and can effectively reduce the total inventory cost with acceptable reliability in operation of power transformer.

8. ACKNOWLEDGEMENT

The authors gratefully acknowledge the Transmission System Maintenance Division at Electricity Generating Authority of Thailand for data support.

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