Model of 33 kV Power Transformer Bushing Risk Management in Urban Substation

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***Abstract*—This paper presents identification techniques to assess the power transformer bushing rating of 33 kV in urban substation by means of state evaluation and magnitude evaluation. Tan delta test with available data is conducted for state evaluation of the transformer bushing, while the selected criteria with updated network data are utilized for magnitude evaluation of the power transformer fleet. Score and weighting techniques are used for the transformer risk assessment. To achieve the proper bushing maintenance, the indices of both assessment of the transformer are plotted in the risk model. Consequently, the maintenance action can be accomplished by nine separated maintenance zones with color indicators such as corrective maintenance, time-based maintenance, state-based maintenance, and online monitoring. In the analysis, 30 power transformers with rating of 33/11 kV are selected for planning the maintenance action of the 33 kV bushing in urban substation. Finally, the reduced transformer risk and improved reliability in the system can be achieved with decreased maintenance costs.**

Keywords-bushing; state evaluation; magnitude evaluation; power transformer; risk management

I. INTRODUCTION

Nowadays, risk assessment with decreased maintenance costs and improved reliability in the electric power network has played a significant role to electricity utilities. In practice, the individual electric utilities select their techniques with available test results to evaluate the power transformer failure and to improve their power system reliability. Power transformer is one of the critical equipment in the power system. The operational states of the system can be mainly influenced by behaviour changing of the transformer. The power transformer is composed of main components: active part, insulating oil, on load tap changer (OLTC), bushing, lightning arrester, tank, and protective devices. Bushing is a significant component that provides the connection of the internal transformer winding and outside oil tank wiring. Transformer bushing failures are often credited as one of the key causes of transformer failures. Hence, the state of the bushing is of high interest to electric utilities. Basically, maintenance actions of power transformer so called asset management consist of four major categories: corrective maintenance, time-based maintenance, state-based maintenance and risk-based maintenance.

Therefore, this paper proposes identification techniques to assess the power transformer bushing in Urban substation that mainly includes four main voltage rating of the transformer: 33/11 kV, 66/11 kV, 230/33/11 kV, and 230/66/11 kV. As a large number of the transformer in the substation is 33/11 kV, the 33 kV bushing is chosen for evaluating the transformer risk by using state evaluation and magnitude evaluation. Tan delta test with available data is conducted for state evaluation of the transformer bushing, while the main criteria with updated network data is utilized for magnitude evaluation of the power transformer fleet. The criteria of the magnitude evaluation include load quantity, N-1 criterion (backup protection), system fault level, transformer age, and social aspects. Score and weighting techniques are concerned for the transformer risk assessment. To achieve the proper bushing maintenance, the indices of both assessment of the transformer are plotted in the risk model. Subsequently, the maintenance action can be accomplished by nine separated maintenance zones with color indicators that are corresponding to corrective maintenance, time-based maintenance, state-based maintenance, and online monitoring. In the analysis, 30 power transformers with rating of 33/11 kV are selected for planning the appropriate maintenance action of the 33 kV bushing in urban substation. Consequently, the reduced transformer risk and improved reliability in the system can be achieved with decreased maintenance costs.

II. BASIC KNOWLEDGE

A. High Voltage Bushing

Bushing is so called condenser bushing that is characterized by a central conductor wound by insulating papers and conductive layers. Its failure can result in serious economic consequences. In practice, the gaps between main insulator and internal surface of porcelain are filled with oil and resin. A high voltage bushing is normally made as a condenser type containing several layers of aluminum foil wounded around conductor and immersed in the oil inside the porcelain housing, called oil immersed paper or OIP. The advantages of the traditional bushing type are low cost and heat dissipating, while the disadvantages are high maintenance cost, transportation, fire and explosion.

As bushing failure cause is mainly from oil leakage, resin impregnated paper or RIP is nowadays increasingly used. In addition, the RIP provides low maintenance cost, easy to transport, keep for storage, superior thermal and electrical performance but the acquisition cost is high. The significant difference between RIP bushing technology and OIP bushing is that the condenser cores in OIP technology are impregnated with transformer mineral oil while the impregnation in RIP technology is fulfilled via a curable epoxy resin to form a solid condenser core. Regarding bushing state assessment, main identification methods are electrical tests and visual inspection. The electrical tests are routine offline testing specified by manufacturers, while the visual inspection is an investigation with human senses such as eyes, noses and ears. Practically, the tests are done every 5 years, while the inspection is done almost every day.

B. Asset Mangement

Normally, maintenance strategy of power transformer includes periodic routine inspections, overhauls, maintenance and state monitoring as well as supplemented inspections as determined by asset state. Maintenance is mainly divided into four actions as follows.

1) *Corrective maintenance (CM):* Repairing transformer is performed when the transformer fails.

2) *Preventive maintenance (PM):*

   a) *Time based maintenance (TBM):* Inspecting transformer is done regularly with a routine period.

   b) *State based maintenance (CBM):* Repairing transformer is done regarding the defined state of the transformer.

3) *Reactive maintenance (RM):* Maintenance action is done directly following unforeseen circumstances such as accident and damage from environmental factor.

4) *Risk based maintenance (RBM):* System risk is reduced by proposing risk model.

C. Scoring and Weighting Techniques

Scoring means that the considered criteria are scored following planned limitation. For instance, diagnostic test for state evaluation is separated into 5 scores: score 1 for very good state, score 2 for good, score 3 for moderate, score 4 for poor and score 5 for very poor. Weighting means that the considered items are weighted showing ascendant priorities. The score and the weight of each criterion are discussed and provided by the experts in the utilities.

D. State Assessment of High Voltage Bushing

The state assessment of the high voltage bushing is performed by the diagnostic test only that is tan delta evaluating the integrity of the insulation system of the bushing. The visual inspection is regardless because the utilities fix the bushing problems from visual inspection immediately. The tan delta value is compared to the commissioning value to achieve the scores. The limitation of the tan delta test is categorized into five scores as written in Table I. For example, the score of the tan delta less than 1.1 times of the commissioning value is 1 with very good state. If the tan delta is greater than 2 times, the score will be 5 for very poor state.

TABLE I. LIMITATION OF TAN DELTA

Times of Commissioning	**Score**	**State**
<1.10	1	Very Good (VG)
1.10-1.25	2	Good (G)
1.26-1.50	3	Moderate (M)
1.51-2.00	4	Poor (P)
>2.00	5	Very Poor (VP)

E. Magnitude Assessment of High Voltage Bushing

The magnitude assessment of the high voltage transformer means its operating characteristics: load quantity, N-1 criterion, system fault level. Transformer age, and social aspects, as written in Table II.

TABLE II. HV TRANSFORMER MAGNITUDE CRITERION

Magnitude Criterion
Load Quantity
N-1 Criterion
System Fault Level
Transformer Age
Social Aspects

The scores of the magnitude criteria include five levels. For instance, the scores of the social aspects are summarized in Table III.

TABLE III. SCORE OF SOCIAL ASPECTS

Detail	**Score**	**Importance**
Suburban	1	Very Low (VL)
-	2	Low (L)
-	3	Moderate (M)
Urban	4	High (H)
Industrial	5	Very High (VH)

The magnitude criterion of the transformer provides their scores that are calculated together with their weighting numbers in order to reach the magnitude index (%II), as written in (1).

$$\%II = \frac{\sum_{i=1}^{5}(S_i * W_i)}{\sum_{i=1}^{5}(S_{max,i} * W_i)} * 100$$

Where S_i means individual score;

$S_{max,i}$ is maximum score; and W_i is weighting number.

F. Risk Management Model

The combination between the state index and the magnitude index proposes the model of risk management. The first index is on y-axis while the latter index is on x-axis. The obtained state and magnitude values of the transformer are plotted as a coordinated point in the risk model providing nine recommended maintenance zones with color indicators, as shown in Fig. 1.

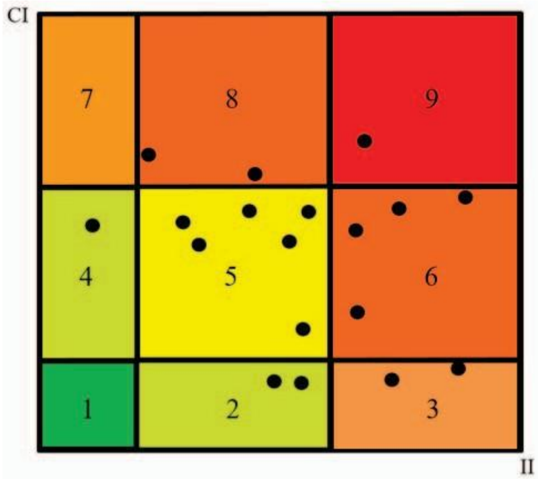

Figure 1. Bushing risk maintenance model

The maintenance action of the nine zones is summarized in Table IV. For example, corrective maintenance is recommended for the transformer in zone 1 that is the lowest risk with very good state (VG) and very low magnitude (VL). Repair, replace or refurbish is needed immediately for the transformer in zone 9 that is the highest risk with poor (P) and very poor (VP) state as well as high (H) and very high (VH) importance.

TABLE IV. MAINTENANCE ACTION

Zone	CI	II	Maintenance Action
1	VG	VL	Corrective Maintenance (CM)
2	VG	L&M	Time-based Maintenance (TBM)
3	VG	H&VH	State-based Maintenance (CBM)
4	G&M	VL	Corrective Maintenance (CM)
5	G&M	L&M	Time-based Maintenance (TBM)
6	G&M	H&VH	CBM + Online Monitoring
7	P&VP	VL	Repair/Replace when fail
8	P&VP	L&M	Repair/Replace/Refurbish with economic concern
9	P&VP	H&VH	Repair/Replace/Refurbish immediately

III. RESULTS AND ANALYSIS

A. Statistical Data

The transformers installed in Urban substation mainly are with rating of 33/11 kV, 66/11 kV, 230/33/11 kV, and 230/66/11 kV. The percentage of these transformer fleet is shown in Fig. 2. The highest percentage of the transformers is 73% with 33/11 kV rating, while the lowest one is 1% with 230/66/11 kV rating.

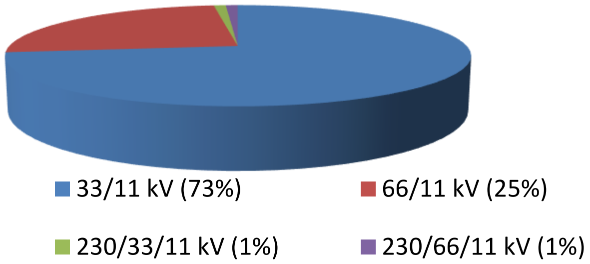

Figure 2. Percentage of transformers with respect to voltage rating

B. State Assessment

Thirty transformers rating of 33/11 kV are selected in the analysis. The tan delta values (TD) compared to the commissioning values are summarized with their state in Table V. The result shows that the transformer T_6 and T_{21} are in very poor state with 2.35 and 2.89 times of the commissioning values, respectively. Four transformers with poor state are T_{12}, T_{18}, T_{23} and T_{26}.

TABLE V. STATE ASSESSMENT OF 30 TRANSFORMERS

T	TD	S	Condition	T	TD	S	Condition
1	1.31	3	M	16	0.77	1	VG
2	1.49	3	M	17	1.3	3	M
3	0.69	1	VG	18	1.99	4	P
4	1.33	3	M	19	0.63	1	VG
5	1.42	3	M	20	0.76	1	VG
6	2.35	5	VP	21	2.89	5	VP
7	0.83	1	VG	22	0.67	1	VG
8	1.24	2	G	23	1.97	4	P
9	1.47	3	M	24	1.38	3	M
10	0.89	1	VG	25	1.07	1	VG
11	0.8	1	VG	26	1.51	4	P
12	1.64	4	P	27	0.86	1	VG
13	0.8	1	VG	28	0.74	1	VG
14	0.99	1	VG	29	0.24	1	VG
15	0.79	1	VG	30	0.55	1	VG

C. Magnitude Assessment

The magnitude index of the 30 transformers rating of 33/11 kV are calculated and summarized in Table VI. The result shows that the transformers T_9, T_{10}, T_{16}, T_{18}, T_{26} and T_{27} are in very high importance. Seven transformers with high magnitude to the network are T_5, T_8, T_{11}, T_{19}, T_{24}, T_{25} and T_{28}.

D. Risk Management Model

The model of the bushing risk management is developed with the 30 transformer data as shown in Fig. 4. The result shows that the transformer T_{18} and T_{26} are in zone 9 with the highest risk. Hence, the recommended maintenance action is that the transformer bushings should be repaired, replaced or refurbished immediately. Four transformers are analyzed in the eighth zone in which repair, replace or refurbish action with economic concerns is recommended.

TABLE VI. MAGNITUDE ASSESSMENT OF 30 TRANSFORMERS

T	%II	Importance	T	%II	Importance
1	48	M	16	81	VH
2	36	L	17	38	L
3	45	M	18	85	VH
4	36	L	19	80	H
5	75	H	20	36	L
6	40	L	21	41	M
7	2	VL	22	34	L
8	73	H	23	39	L
9	87	VH	24	77	H
10	85	VH	25	76	H
11	72	H	26	85	VH
12	37	L	27	81	VH
13	38	L	28	72	H
14	36	L	29	45	M
15	42	M	30	50	M

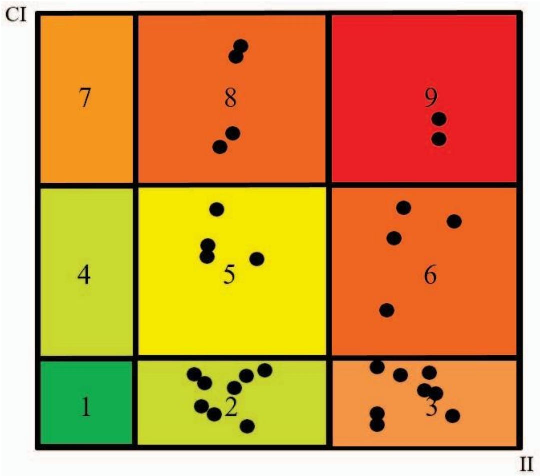

Figure 4. Risk management model of transformer bushing

IV. CONCLUSION

The risk maintenance model of the transformer bushing rating 33 kV installed in Urban substation is developed by means of the state and the magnitude indices. The state index is evaluated by the diagnostic test, tan delta, while the magnitude index is evaluated by the transformer operation characteristics: load quantity, N-1 criterion, system fault level, transformer age, and social aspects. The score and weighting techniques are applied for the assessment. The nine zones of the bushing maintenance are proposed and recommended. The 30 power transformers with rating of 33/11 kV are selected in the analysis. Two transformers with the highest risk in the ninth zone are T_{18} and T_{26}. Thus, immediate repairing, replacing or refurbishing the transformer bushings is recommended for their maintenance task. Four transformers analyzed in the eighth zone are T_6, T_{12}, T_{21} and T_{23} so that their bushings should be repaired, replaced or refurbished with economic concerns. Consequently, the the high voltage bushing failure existence is reduced with the developed risk maintenance model. Finally, the reliability of transformers that affect the network availability can be improved.

ACKNOWLEDGMENT

The authors gratefully acknowledge King Mongkut's University of Technology North Bangkok (KMUTNB) and Urban Electricity Authority for supporting this work and providing the data.

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