Asset Management of Power Transformer Protective Devices in Transmission System

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Abstract

Electrical utilities face high risks on acquisition and maintenance costs of their assets and try to achieve maximum utilization of their existing assets during the lifecycle. Asset management especially reliability centered maintenance is utilized for reducing maintenance risk. Power transformer is one of the most expensive components in electric power transmission. As protective devices are one of vital components of power transformer, asset management of power transformer protective devices in transmission system is proposed for preventing incipient faults in transmission system. Condition assessment and importance assessment are performed to set up maintenance tasks properly. The protective devices of loading transformers rating of 115/22 kV and tie transformers rating of 230/115 kV are selected to support the proposed model of maintenance risk reduction. Reliability and stability of the network are consequently improved.

Keywords: condition assessment, importance assessment, maintenance task.

1. Introduction

Asset management has played a key role in power system equipment of electrical utilities, especially power transformer that is one of the most critical components in high voltage substation and electric power transmission⁽¹⁾. In addition, the transformer asset management is generally considered due to the substantial investments in the power transformers and the importance of the transformers as one of vital factors that result in the system reliability⁽²⁾. In

electricity generation plants, power transformers transform the voltage of the generator to a higher level for the transmission of electricity in the main grid. Subsequently, the voltage must be transformed to a lower voltage so that the utilization of electrical energy can be done in various purposes. Power transformer contains a number of components: active part, bushing, arrester, on load tap changer, insulating oil, tank and protective equipment. Failures on any components can affect catastrophic consequences to the network.

As the protective devices are one of the defected components of the transformer, asset management of the protection should be performed. Condition assessment of the transformer protective devices is done by using visual inspection. Scoring and weighting techniques are applied to the assessment for classifying the condition into satisfied levels of maintenance strategies. Importance assessment of power transformer in the network is also performed for classifying the transformer importance into maintenance ranking.

This paper aims to present the proposed model of asset management of power transformer protective devices in the transmission system by applying the condition and the importance approaches with scoring and weighting techniques. The condition of the protection is assessed by using the visual inspection that is done every two weeks or a month, while the importance of the transformer is assessed by using operating characteristic of the transformer. Subsequently, both assessments are represented by color indicator: green, yellow and red. The data of the loading and tie transformers is used for the analysis. The asset management techniques for the protection can be then

achieved with higher reliability and stability of the transformer in the transmission system.

2. Asset Management Approach

2.1 Fundamental Asset Management

Asset management⁽³⁻¹⁰⁾ is systematic and coordinated activities in which an organization optimally manages its assets, associated performance, risks and expenditures over their lifecycle for achieving its organizational strategic plan. Electrical utilities face a trouble on not only high acquisition cost of their assets especially power transformer, but also high maintenance cost during lifetime of power transformer. Thus, most of them need the asset management to maximize the utilization of their costly transformers. The successful asset management task can prolong the transformer lifetime with proper maintenance strategies and suitable schedule plan.

2.2 Power Transformer Protection

Normally, power transformer consists of various main components: active part, bushing, arrester, on load tap changer, insulating oil, tank and protective devices. The un-scheduled outages of the transformers due to unexpected failures are catastrophic in many cases to the network. The failures occurred from the protective devices are one of main causes affecting the transformer shutdown. The transformer protection involves eight devices as shown in Fig. 1.

(a) Transformer pressure relief

Transformer pressure relief (TPR) is installed on top of the tank cover or at a high position on the tank wall. It is utilized for relieving the pressure when high pressure from internal arc occurs, and can minimize the loss of insulating oil. The pressure relief device as shown in Fig. 1(a) operates if a large pressure builds inside tank caused by heavy arcing and heating affecting the oil to boil and bubble.

(b) Sudden pressure relay

Sudden pressure relay (SPR) is installed high up on the tank wall. It aims to alarm if there is a sudden pressure rise inside the tank. The relay as shown in Fig. 1(b) operates sensitively for only a little of pressure rising, caused by a small electrical fault inside the tank.

(c) On load tap changer pressure relief

On load tap changer pressure relief (OPR) is used for releasing the pressure when high pressure appears inside

OLTC compartment. The device is shown in Fig. 1(c).

(d) On load tap changer oil flow relay

On load tap changer oil flow relay (OFR) is used for protecting high pressure inside OLTC compartment due to arcing of connection inside the OLTC tank. It operates when the speed of oil flow exceeds the defined limit. The relay is shown in Fig. 1(d).

(e) Buchholz relay

Buchholz relay (BHR) is used for protecting incipient faults that generate a large amount of combustible gases in insulating oil. The relay operates when the quantity of accumulated gases over the defined limit. The relay is shown in Fig. 1(e).

(f) Rubber bag rupture

Rubber bag rupture (RBR) is used for checking the air bubble flowing into the insulating oil. When the rubber as shown in Fig. 1(f) is ruptured, oil leakage and oil level in sight glass require checking for damages.

(g) Oil temperature indicator

Oil temperature indicator (OTI) is used for measuring the top oil temperature of the power transformer. The indicator is shown in Fig. 1(g).

(h) Winding temperature indicator

Winding temperature indicator (WTI) is used for measuring the hot spot temperature of the transformer windings. The indicator is shown in Fig. 1(h).

Fig. 1. Protective devices of transformer.

2.3 Transformer Protection Asset Management

The asset management of the protective devices can be classified into the following activities, as shown in Fig. 2.

Fig. 2. Transformer protection asset management.

2.4 Condition Assessment

The condition assessment⁽¹¹⁻¹³⁾ of the transformer protection is done by using the up-to-date data of visual inspection of individual protective devices. Electrical testing which is basically done and recorded for assessing the condition of other major components of the transformer is not necessary for the protective devices.

(a) Visual inspection

Visual inspection is physical inspection of transformer exterior. It reveals the condition information by using human senses of experienced staff. The inspection period is set by the electric utilities or manufacturers such as every two weeks or one month. The visual inspection of the transformer protection is gathered in Table 1. Oil leakage and operation of the protection are checked by the utility staff every two weeks for protecting the incipient faults.

Table 1. Visual inspection of protection

Protective device	Visual inspection
Transformer pressure relief	Oil leakage
Sudden pressure relay	
OLTC pressure relief	
OLTC oil flow relay	
Buchholz relay	
Rubber bag rupture	
Oil temperature indicator	Operation
Winding temperature indicator	

2.5 Importance Assessment

The importance assessment⁽¹⁴⁻¹⁵⁾ of the transformer protection is performed by using the operating characteristics of the transformer, as written in Table 2.

Table 2. Importance criteria

Importance items
Load factor
Load shedding
N-1 criterion
System stability
Damage of property
Social aspects
Pollution

2.6 Maintenance Action

When asset management is concerned to maximize the asset utilization and to reduce the maintenance risk, maintenance plan will be clarified. The maintenance types are classified into corrective maintenance, preventive maintenance, and reliability centered maintenance, as shown in Fig. 3.

Fig. 3. Classification of maintenance action.

2.7 Scoring and Weighting Technique

Scoring⁽¹⁶⁾ relies on transformer condition experts. Relative terms such as “normal” and “degradation” refer to operating condition, industry accepted levels, or baseline levels of considered devices. Weighting factor means weighting number of each considered criteria that imply a precision to the assessment.

The assessment methodology is performed by using the scoring and weighting technique, as written in (1).

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

Where $\%AI$ means assessment index; S_i means individual score; $S_{max,i}$ is maximum score; W_i is weighting factor; and n is the number of considered items.

2.8 Maintenance Selection

Maintenance task selection for the transformer protective devices follows their obtained condition. The maintenance is divided into three levels, as shown in Fig. 4.

Fig. 4. Maintenance tasks of protective devices.

The percentage of the condition assessment index, $\%AI_C$, is defined by the calculation of the scores and the weighting numbers. Routine maintenance is selected for good condition when the $\%AI_C$ is 0-41%; repairing is selected for 42%-68% with suspect condition; and refurbishing is selected for 69%-100% with poor condition. They are represented by green, yellow red indicators, respectively.

When a fleet of the power transformers in the system is considered in the assessment, even the acquisition cost of the protective devices is not expensive, transformer ranking of first maintenance may be necessary. Hence, the ranking will follow the importance assessment as represented by $\%AI_I$ in Fig. 5. Similar to the condition, the obtained $\%AI_I$ is calculated by the scores and weighting numbers of the operating characteristic items. Low transformer importance is for 0-42%; medium importance is for 43%-68%; and high importance is for 69%-100%. They are represented by green, yellow and red indicators, respectively.

Fig. 5. Importance of protective devices.

3. Results and Analysis

As the transformers rating of 115/22 kV and 230/115 kV are mostly installed in the system, their available data is collected and used in the analysis. The 115/22 kV loading transformers are T1, T2, T3, T4 and T5, while the 230/115 kV tie transformers are T6, T7, T8, T9 and T10.

(a) Condition Maintenance Task

The data of visual inspection of the loading transformer protection is written in Table 3, whereas that of the tie transformer protection is gathered in Table 4.

Table 3. Visual inspection of loading transformer

Device	T1	T2	T3	T4	T5
TPR	normal	normal	normal	dry oil stain	dry oil stain
SPR	normal	normal	normal	normal	normal
OPR	normal	normal	normal	normal	normal
OFR	normal	normal	normal	normal	normal
BHR	normal	normal	normal	normal	normal
RBR	normal	normal	normal	normal	normal
OTI	normal	rusty needle	rusty needle	rusty needle	rusty needle
WTI	normal	rusty needle	normal	normal	rusty needle
$\%AI_C$	33.33	42.42	37.88	42.42	46.97
Cond.	good	suspect	good	suspect	suspect

Table 4. Visual inspection of tie transformer

Device	T6	T7	T8	T9	T10
TPR	dry oil stain	dry oil stain	normal	normal	normal
SPR	normal	normal	normal	dry oil stain	dry oil stain
OPR	dry oil stain	dry oil stain	dry oil stain	normal	dry oil stain
OFR	normal	normal	normal	normal	dry oil stain
BHR	normal	normal	normal	dry oil stain	dry oil stain
RBR	normal	normal	normal	normal	wet oil stain
OTI	normal	rusty needle	rusty needle	rusty needle	normal
WTI	rusty needle	rusty needle	normal	rusty needle	rusty needle
$\%AI_C$	45.45	50.00	40.91	51.52	62.12
Cond.	suspect	suspect	good	suspect	suspect

(b) Importance Maintenance Task

The data of importance assessment is written in Table 5 for the five loading transformers and Table 6 for the five tie transformers. The calculated importance index, $\%AI_i$, shows that all loading transformers are in moderate importance. When the condition and the importance are considered together, the transformers T2, T4 and T5 that are in suspect condition are in moderate importance. The descending ranking of repairing the protective devices is T5, T2 and T4. For the tie transformers, the $\%AI_i$ shows that the transformers T6, T8 and T9 are in high importance. In addition, the protective devices of the transformer T9 are maintained firstly due to the highest importance (84.62%) as the transformer has no N-1 criterion and is installed in high pollution location with 31 mm/kV.

Table 5. Importance of loading transformer

Device	T1	T2	T3	T4	T5
load	0.7	0.7	0.6	0.5	0.5
Shed.	no shed	step 3	step 1	step 2	step 1
N-1	yes	yes	no	no	no
system sta.	loading	loading	loading	loading	loading
damage	fire wall	none	oil pitch	oil pitch	fire wall
social	suburb	suburb	suburb	suburb	suburb
pollut. [mm/kV]	16	20	16	16	20
$\%AI_i$	53.85	56.41	58.97	53.85	56.41
Imp.	mod.	mod.	mod.	mod.	mod.

Table 6. Importance of tie transformer

Device	T6	T7	T8	T9	T10
load	0.6	0.7	0.6	0.6	0.5
shed.	step 1	step 1	no shed	no shed	step 3
N-1	no	yes	yes	no	yes
system sta.	loading	tie	tie	loading	loading
damage	fire wall	fire wall	oil pitch	oil pitch	fire wall
social	industry	suburb	suburb	industry	industry
pollut. [mm/kV]	20	20	20	31	16
$\%AI_i$	71.79	58.97	69.23	84.62	53.85
Imp.	high	mod.	high	high	mod.

4. Conclusions

Protective devices of power transformer in electric transmission system also need asset management techniques for reducing maintenance risk, maximizing their utilization and preventing incipient fault occurrences. The transformer protection asset management consists of two indices: condition assessment and importance assessment. Both assessments are used with scoring and weighting techniques to set up maintenance plan. Visual inspection is performed for evaluating the protection condition, while operating characteristic is utilized for evaluating the transformer importance. The indices are represented by three color indicators: green for good condition and for low importance, yellow for suspect condition and moderate importance, as well as red for poor condition and high importance. The transformer protection with poor condition and higher importance is maintained firstly. The maintenance actions of the condition evaluation are routine, repair and refurbish.

Due to available data, the loading and tie transformers are selected for the assessment. The transformer protections of T5 for the loading type and T9 for the tie type are maintained firstly as they are in suspect condition with higher importance than the others. The condition and the importance of the T5 are 46.97% and 56.41%, respectively. Those of the T9 are 51.52% and 84.62%, respectively. Consequently, using this proposed model of the asset management for the transformer protection in the transmission system can reduce the maintenance risk and improve the system reliability as the incipient faults are prevented.

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