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Current Situation and Recent Challenges in Asset Management of Aging T&D Substation Facilities in Japan.

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SUMMARY

In recent years, many initiatives for asset management of substation facilities are reported from various companies. These facilities have been installed to accommodate the increasing power demand, however, most of them are getting aged. It is required to maintain these facilities in order to utilize until their end of lifetime and also maintain the reliability of electric supply. In order to achieve this, asset management is necessary, and this includes the methods of decision making and optimizing the priority for capital investments such as refurbishment of aging facilities, due to the variation in the aging of the equipment.

The works of Service Provider are sufficiently reported including technologies of maintenance/ inspection, evaluating current situations and lifetime, and surveys of analysis of faults in CIGRE technical reports, current WG report and so on. On the other hand, the works of Asset Manager are introduced only for some applications such as the risk evaluation of entire facilities (i. e. Health Index), the evaluation of economic life, and the selecting methods of refurbishment or partial repair.

This paper reports current working for the asset management, and also overview the surveys of CIGRE. For example, organizing quantitative Health Index to level the number of aging equipment to be replaced, standardization of collecting format of failure data for sharing among electric companies, prediction method of the failure rate with limited data samples are reported.

Also we report the repair method corresponding to challenges such as impact on the power system, capability of construction, and maintaining of technical ability.

KEYWORDS

Asset management - Aging transmission facilities - Health Index - Economical life time - Investment strategy

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1. INTRODUCTION

Substation facilities have been installed to accommodate the increasing power demand, however, the timing of which the facilities are installed varies widely and most of them are getting aged. It is required to maintain these facilities to utilize until their lifetime and also maintain the reliability of the electric supply. In order to achieve this, it is necessary to optimize the methods of decision making and priority making for capital investments such as refurbishment of aging facilities.

In this paper, we are organizing the technical trend regarding the asset management of transmission facilities. Also we are reporting the challenges of the asset management and proposing new methods of the decision making and the priority making.

2. THE SURVEYS OF ASSET MANAGEMENT IN CIGRE

The surveys of 18 papers regarding the asset management out of CIGRE technical report (A2, A3, B3, C1 and D1) , reports of CIGRE Paris session 2014, and WG reports currently working have been carried out. The survey results have been organized in Figure 1 according to the asset management process, which consists of 4 phases; maintenance, evaluation of current situations, prediction and strategy.

The works of Service Provider sufficiently reported including technologies of maintenance/ inspection, evaluating current situations and lifetime, and surveys of analysis of faults based on CIGRE technical reports and current WG report and so on.

Meanwhile, the roles of Asset Manager, such as the risk evaluation of entire facilities (i.e. Health Index), the evaluation of economic life, and the selecting methods of refurbishment or partial repair, are introduced through some applications.

	Item	Measurement	Situation	Bibliography
technologies of maintenance/ inspection	Preventive maintenance	TBM, CBM, RCM	Maintenance and inspection method is eveloped.	TB 165, 381, 445
	Follow-up maintenance	CM	–	–
	Condition monitoring	On-line monitoring	Diagnostic method in accordance with IEC61850 is organized.	TB 472, 525 IEC61850
Evaluating Current situations	Diagnostic method	Electrical tests	Test items are generalized.	TB 165, 368, 445
		Dissolved gas analysis in oil	Defined by IEC60559.	TB 300, 445, 541 IEC60559
	Evaluation	Health Index	Some application examples have been reported recently, though still at an early stage.	TB 248, 541 2014 CIGRE PARIS SESSION, B3-214, A2-101, A2-103, A2-107
Prediction	Residual life diagnosis	Polymerization degree evaluation	Index such as CO+CO2 and Furfural are proposed for transformer. Nothing for other facilities.	TB 227, 300, 393
	Failure experience	Survey of fault rate	Survey of fault rate of transformers and circuit breakers has been done by CIGRE.	WG A2.37, A3.06
			Necessary to standardize collecting format of fault data.	TB 227, 298
		Prediction of fault rate	Fault rate prediction method from failure experience is not developed.	2014 CIGRE PARIS SESSION A2-101
	Life expectancy	Deterioration mode	Determinant deterioration mode for lifetime is heat deterioration.	TB 393
		Setting of life expectancy	Life expectancy is not defined, predicted by experience.	TB 300, 422, 597
Strategy	Policy development	Asset management process	Application examples are shown but not standardized.	TB 300, 422, 597
	Economical evaluation	Life cycle cost evaluation	Defined by IEC60300-3-3.	TB 248, 252 IEC60300-3-3
	Decision making	Determination of replacement and repair	–	–

Figure 1 Asset management process and current technical trend

In the asset management, the data of maintenance/inspection and evaluation of current situation which are prepared by Service Provider are utilized by Asset Manager and Asset Owner in their policy decision. Also, degree of communication between Service Provider and Asset Owner has to be reinforced.

The challenges in the asset management are identified as follows;

a. Arrangement of Health Index showing condition evaluation of each facility
Recently, examples of actual applications examples have been reported from some countries. Evaluation items are being identified gradually, however, the way of weighting them are not developed. Also the Health Index items of transfomers are practical, whereas those of circuit breakers are not, due to the lack of practical external diagnostic technologies.

b. Collection of fault data for failure rate prediction
Although the fault records is important, those data can not be shared among users because each of them use original data collecting format.
As the failure rate of transmission facilities is very low, a large amount of data samples are required to accurately predict the failure rate in the future. And it is necessary to have a standardized format to collect and share failure records.

c. Prediction of failure rate
It is necessary to know the timing and the speed of incline of the failure rate bathtub curve for an accurate prediction. However, the prediction method of the failure rate based on limited data samples is not developed.

d. Setting of life expectancy and determination of refurbishment and repair
Except for transfomers, the lifetime evaluation method of facilities has not been developed. The lifetime expectancy of facilities can be empirically estimated as shown in Table 1 [1], but there is a gap between 10 to 40 years against the real value. In addition, quantitative determination criteria tor refurbishment and repair has not been developed.

Table 1 Lifetime expectancy of each facility [1]

Infrastructure (buildings, support structures, foundations, roads, fences etc.)	60 – 80 years
Conductors, insulators	30 – 70 years
Circuit breakers, disconnectors	30 – 50 years
Power and measurement transformers	30 – 50 years
Control and protection devices	20 – 30 years
SCADA, Intelligent Electronics Devices (IED)	15 – 25 years
Secondary equipment and circuitry	10 – 45 years

3. CHALLENGES OF ASSET MANAGEMENT IN JAPAN

As discussed in the last chapter, there are still challenges in asset management such as development of the Health Index system, standardization of data collecting format, and formulation of a prediction method for failure rate.
Also, to perform the asset management for substation system as a whole, it is necessary to consider challenges such as the impact on the power system, capability of construction, and maintaining of technical ability.
In Japan, electric power companies, manufacturers, universities and research institutes are cooperating to respond to the challenges mentioned above. We will report the activities in this paper.

3.1. Index showing condition evaluation of each component (Health Index)

Transmission facilities, even if they are the same type, are subjected to different stresses caused by not only the differences of their rated values and duties, but also their environmental conditions (impact of ambient temperatures, salt pollution and so on), load factor, and the number of operations. In the asset management, transmission facilities have to be evaluated quantitatively and prioritized using an index considering not only the aging of facilities, but also their current conditions and inherent risks.

Table 2 shows the Health Index for 66 kV distribution transformer used in a Japanese electric company. In addition to the conditions of current facilities such as age, result of dissolved gas analysis and oil leakage, evaluation is done for specific facilities, using index points, set based on possible repair cost and impact of inherent risk items according to its failure record.

Table 2 Health Index items for 66 kV distribution transformers

Index	Points	Notes
Age	n	1 point/operating year
Dissolved gas analysis in oil	10	Over Alarm level II
Trace PCB in insulating oil	6	Exceeding defined limits
Oil leakage from transformer	5	Leakage from one area
	10	Leakage from several areas
	20	High loss transformer using Hycar cork for gasket, and has leakage from several areas.
Specific equipments	47	Winding configuration with high probability of lightning-caused failure
	5	Risk of core corner damage due to aging
	10	RIP bushing of Company A (Risk of insulation breakdown due to aging)
	3	RIP bushing of Company B (Risk of insulation breakdown due to aging)
LTC with no replacements	5	Transformer using LTC with no replacements

3.2. Consolidation of facility/failure data

In asset management, it is necessary to predict the future failure rate transmission facilities, and to do that, collection of failure data is required.

On one hand, the failure rate of transmission facilities is low, and to be able to predict the failure rate, large amount of facility data is needed. Accordingly, it is necessary to collect and analyze data from not only one power company but all power companies worldwide.

In Japan, 11 users and 9 manufacturers are cooperating in the standardization of input data, collecting and analyzing facility/fault data based on a unified definition. Table 2 shows the template and items of a maintenance record for a transfomer which was standardized in 2009 [2]. It includes items such as specification, operation record, failure record, repair schedule, dissolved gas analysis data, inspection results, test/diagnosis results.

In order to predict future failure rates accurately, it is necessary to standardize a platform internationally, and to consolidate the each of the collected data as showing Table 3.

Table 3 Items for database of transfomers

Category	Items for database
Facility data	Manufacturer, type, serial number, year of manufacture, rated value (voltage, capacity, etc), type of conservator, amount of insulating paper, oil capacity
Operation record	Load factor, ambient temperature, environment
Inspection data	Results of inspection (oil leakage, crack/deformation, oil level, protective relay operation), Results of dissolved gas analysis Results of electric test (ratio, winding resistance, low voltage excitation current, partial discharge, characteristic of insulation oil, LTC operation, insulation resistance, charged potential, FRA)
Repair record	Details of repair
Fault record	Details of fault, cause of fault, measurements

3.3. Prediction method of the failure rate

In order to grasp the failure rate and economic life (planned refurbishment more advantageous in regards to cost compared to carrying out repairs by Corrective Maintenance (CM)) of the current facilities, it is required to evaluate quantitatively the increase in failure rate caused by equipment aging. Figure 2 shows the results of fault analysis of a vacuum circuit breaker of a 6 kV switchgear in a Japanese electric company.

The hazard function in Figure 2 is used to express the failure rate of an operating equipment at the referenced year, and is approximated by the Weibull distribution as per the following;

$$\lambda(t) = -\frac{dR(t)}{dt}/R(t)$$

$\lambda(t)$: Hazard function

R(t): Reliability function*

* The ratio of number of operating (i.e. no-fault) equipment at the referenced year to number of equipment at the initial year

$$R(t) = 1 - F(t)$$

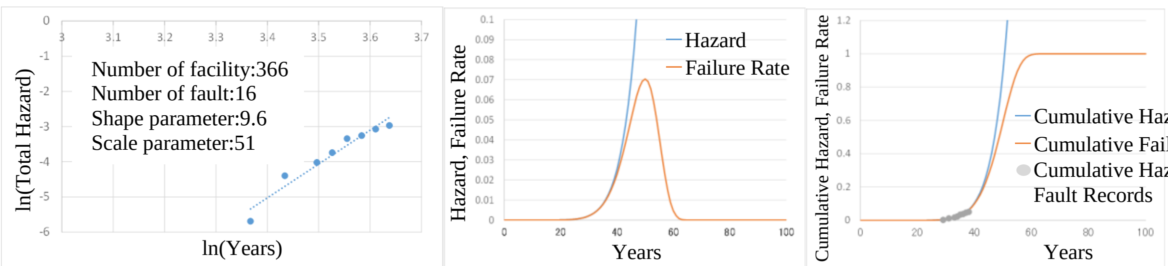
F(*t*): Unreliability function

$$F(t) = 1 - \exp\{-(t/t_s)^m\}$$

F(*t*): Cumulative failure rate by Weibull function

m : Shape parameter

t_s : Scale parameter



(a) Hazard plot (b) Hazard and Failure rate (c) Cumulative Hazard and Failure rate

Figure 2 Fault analysis of vacuum circuit breaker of 6 kV switchgear

Current facilities have been operating for approximately 30-40 years and by applying the hazard function to the aging distribution, the future failure rate can be obtained as a bathtub

curve. In the case of fault example in Figure 2 (c), a rapid increase in faults after about 40 years of operation is predicted.
By multiplying repair cost to this result, it is possible to estimate repair cost by CM and evaluate the life cycle cost, and in turn leading to strategic decision making.

3.4. Asset managemant as a substation system

When it comes to the asset management as a substation system, not only the current conditions and priorities of each facility, but the typical challenges in substations must be factored in as we. These challenges include power system factors caused by plan or change in power demand, coordination of the number of field workers and maintaining technological competance, and the increase in obsolete type equipment.
In Japan, for transformers and early type gas insulated switchgears (GIS), guidelines for life extension, partial repair, and refurbishment of substation system are determined upon assessment of the substation's impact to the power system.
Figure 4 shows the guideline for the early type GIS [3]. First step is assessment of equipment condition. In the second step, life extension or refurbishment is decided, considering the possibility of life extension. In the next step, it is assessed decided once more from the viewpoint of economic evaluation. Refurbishment priority is decided based on evaluation items in Table 4. In the refurbishment planning step, site condition, system reliability, standardization of investment, and capability of construction are considered.

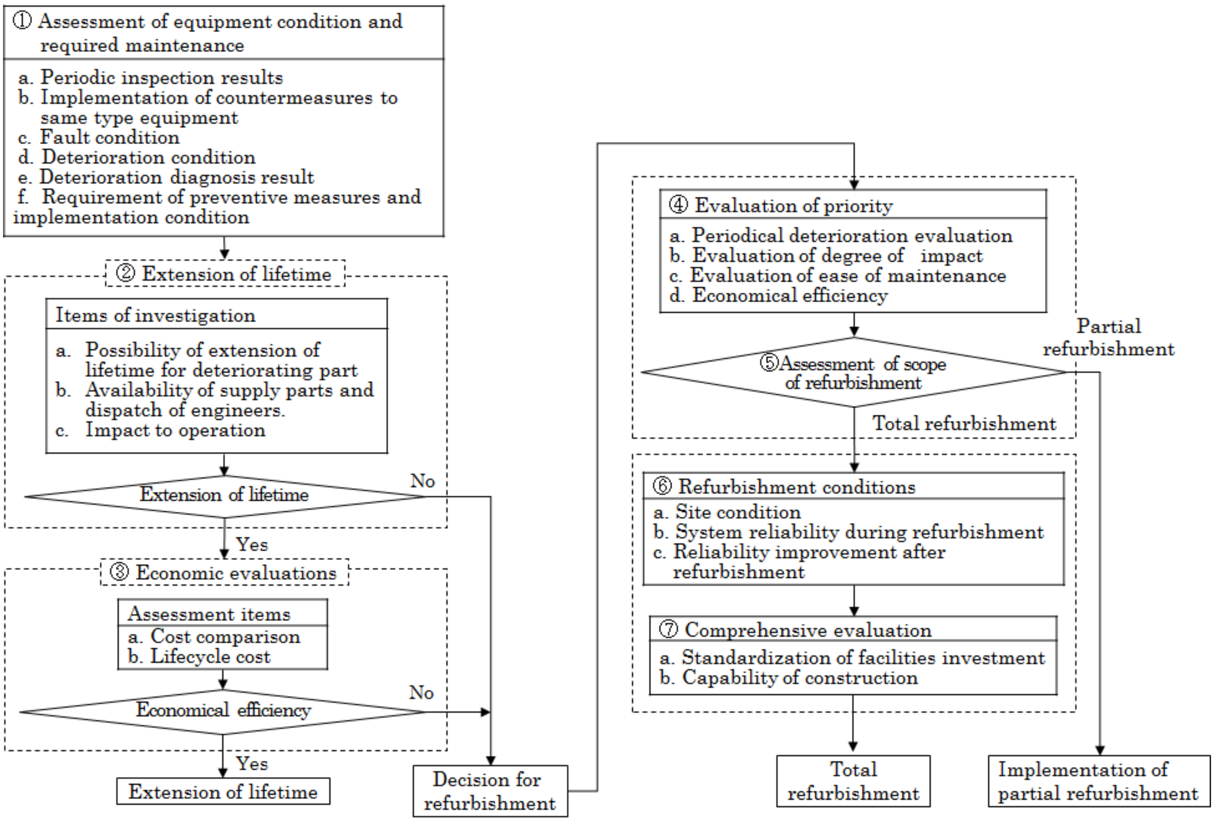


Figure 4 Repair Guideline of early GIS

Table 4 Evaluation items for refurbishment priority

Evaluation Item				Level of Evaluation 1	Level of Evaluation 2	Level of Evaluation 3	Evaluation Criteria	Evaluation Weight	Point
Degree of impact	System	System Switching		—	—	N/A			
		Operational constraint		—	—	Yes			
		Availability of solution to operational constraint		—	—	No			
		Period until solution of operational constraint		Days	Weeks	Months			
	Constraints of construction	Outage area		Target area	Affected surrounding area	Total outage			
		Workability	Bellow	—	—	No			
			Bus Spacer	—	1	No			
	Others	Importance of substation		Low	Medium	High			
		Disaster risk		—	—	Yes			
	(Optional)								
Maintenance	Evaluation of maintenance	Manufacturing of parts	Bus	Substitute	—	N/A			
			GCB	Substitute	—	N/A			
			DS	Substitute	—	N/A			
		Procurement of parts	Bus	Days	—	Months			
			GCB	Days	—	Months			
			DS	Days	—	Months			
		Experienced Workers	Availability (TA)	N/A after several years	—	N/A			
		Skilled Workers	Availability (Cause investigation)	N/A after several years	—	N/A			
		(Optional)							
	Economical efficiency	Maintenance Cost	Inspection Costs	—	—	¥○○			
			Repair Costs	—	—	¥○○			
			Other Costs	—	—	¥○○			
		(Optional)							

4. EXAMPLES OF ASSET MANAGEMENT

Using the approach reported in Chapter 3, the priority of transmission facilities can be decided by not only aging but also by indexing the condition of facilities, impact of faults and economic loss. Figure 5 shows an example of adopting this idea to a GIS installed in a Japanese electric company [4]. For each manufacturer's GIS type, risk items such as maintainability of aging facilities, presence of implementation of countermeasures to same type equipment, failure rate, and production of discontinued parts, are evaluated by scoring points in Table 5. In addition to leveling the number of planned replacements, by utilizing the characteristics of each manufacturer's facilities, an appropriate maintenance is made possible based on the facilities' soundness. Furthermore, cooperation of facilities countermeasures and regular maintenance can be realized.

Moreover, in the future, combining the asset management methods to the capital management system will link Service Provider and Asset Owner/Asset Manager more strongly.

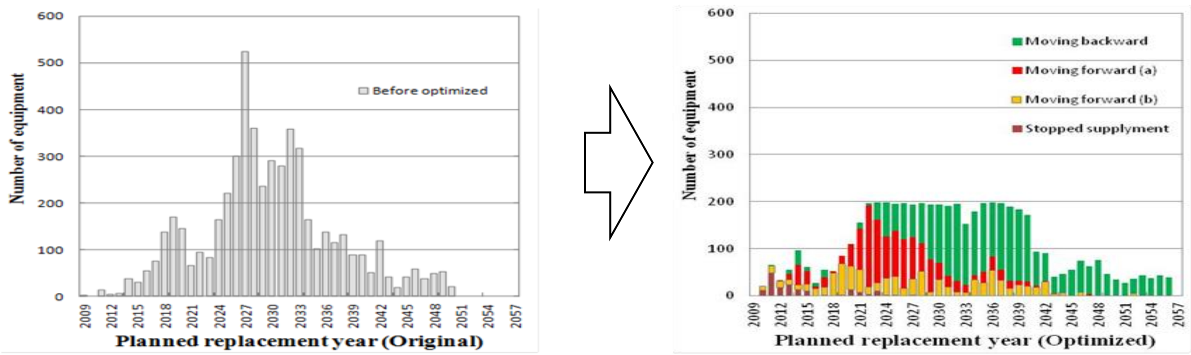


Figure 5 GIS refurbishment schedule based on the risk management in Japanese electric company

Table 5 Examples of evaluation for each GIS type

Developed Year	Voltage [kV]	Manufacturer	Type	Number in service	Evaluation: Maintain-ability	Evaluation: Measures of the same type [Number of measures]	Evaluation: Failure rate [x10^{-3}/year x number]	Evaluation: Malfunction rate [x10^{-3}/year x number]	Evaluation: Supply stop of parts [Since year]	Score	Remarks	Replacement plan
1968	154,77	A	A-a	227	+ +	- 1	+ + 13.69	+ + 0.44	- -2015	10	Good maintenability Stopping parts supply	Negotiation for parts supply and postpone replacement
1970	275-77	B	B-a	293	-	- - 7	- - 35.40	+ + 1.21	+ +	7	Many Fatal failure Failure rate is increasing	Moving forward (b)
1977	77	C	C-a	228	-	+ + 0	- - 31.56	- -2.56	- -2016	4	Failure rate is increasing Stopping parts supply	Moving forward (a)
Legends					+ + Easy - Difficult - - Much Difficult	+ + 0 - 1 - - Several	Average : 22.10 + + Below - Near average - - Above average	Average : 1.56 + + Below - Near average - - Above average	Supply stop of parts + + No - - Yes	score + + 2 - 1 - - 0	■ Moving backward ■ Moving forward (a) ■ Moving forward (b)	

5. CONCLUSION

In Japan, the economic lifetime is evaluated from prediction of future failure rate and evaluation of Health Index, and refurbishment schedule is formulated based on these evaluations. By these methods of the asset management, effectiveness of investment which takes into consideration of life cycle cost can be visualized, and quantitative explanation to Asset Owner and Stake Holders can be made. In addition, the planned refurbishment can be leveled, and limited fund and human resources can be utilized. It is beneficial not only for electric companies, but also for all stakeholders such as manufacturers and construction companies.

In the 2015 report [5] published by IEC Market Strategy Board, it is reported "A centralized international database of electricity equipment failures and historical performance records would bring massive benefit to all stakeholders." In addition to deepening technical knowledge considering the asset management in CIGRE, it is necessary to develop advanced proposals by uitilizing knowledge of CIGRE.

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