Integration of Asset Management and Smart Grid with Intelligent Grid Management System

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ABSTRACT

Electric power transmission and distribution (T and D) systems are composed of a great deal of aged apparatus, which may cause a decrease in reliability owing to their deterioration. In order to maintain high efficiency and high quality in T and D systems, the authors have proposed an "intelligent grid management system" (IGMS), which determines the optimum maintenance strategy and optimum power flow control based on condition monitoring and diagnostic results of the operating power apparatus. This means that the IGMS essentially includes both concepts of an asset management system and a smart grid. Further, the IGMS optimizes power flow routes and maintenance plans based on the failure risk, T and D loss, overload operation, life estimation of the power apparatus, customer outage, and other metrics. The impact of individual apparatus failure affects the entire T and D system's performance, causing blackouts and secondary failures. Reduction in reliability of whole system is highly dependent on ageing of the materials. The IGMS evaluates all of the events occurring in the T & D system as the cost. Additionally, the risks are evaluated in the cost according to the impact of the failure rate estimated by the condition monitoring diagnosis results of the power apparatus. Insulation system determines the transition in reliability and maintenance cost of the system. In this paper, the IGMS is applied to T and D system models including aged apparatus, such as transformers and circuit breakers, and suitable power flow routes and maintenance strategies are derived. Consequently, by the effective application of the IGMS, the system reliability can achieve an optimum state, and the total cost can be minimized.

Index Terms — **Energy management, diagnosis, risk analysis, maintenance, condition monitoring, smart grid, asset management, power flow control, power grids.**

1 INTRODUCTION

HIGH reliability and quality in electric power supply systems are required because of a rise in the standard of living. A "smart grid" is proposed as one of the solutions of this problem. A T and D system is composed of many apparatus that are usually aged individually, and suitable maintenance that ensures the reliability of a T and D system is required. The reliability of a T and D system usually increases with maintenance cost. On the other hand, the cost of an event such as an accident or an outage decreases as the system reliability increases [1–4]. Furthermore, when electric power flows through low-efficiency apparatus and long-distance transmission lines, the power delivery cost should increase. To optimize the balance between cost efficiency and quality improvement in an electric power supply, it is necessary to diagnose the present condition and to estimate the future performance of operating apparatus in the T and D system based on a condition monitoring and diagnosis (CMD) system. Most of significant parameters in terms of the reliabilities and reduction in reliabilities of materials are taken from literatures from the point of view of performance and ageing of insulation materials. Our purpose is to operate a T and D system effectively by maintaining a balance between cost and quality from a short time frame to long periods of years.

As a method that solves this problem, we propose an intelligent grid management system (IGMS). We have been conducting research on the IGMS for several years [5–12]. In this paper, the concept, algorithm, and effectiveness of IGMS are presented. The objective function of the IGMS includes both: 1) the costs of the T and D loss and the outage loss

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according to the present performance, 2) the costs of the failure loss and apparatus maintenance cost by future performance of the entire T and D system optimization. Thus, the optimal control that includes the present power flow and the future maintenance of a T and D system is achieved. Consequently, IGMS is the integration of power flow control and maintenance technology based on condition monitoring of power apparatus.

2 CONCEPT AND ALGORITHM OF IGMS

2.1 BASIC CONCEPT

The total T and D cost reaches a minimum when a balance between cost and quality of electric power supply is found, and then, the T and D route is selected. Thus, the cost and reliability must be evaluated for the entire T and D system, and not for individual apparatus. The concept of the IGMS is shown in Figure 1. The present performance and the history of apparatus operation and maintenance are acquired by diagnostic systems and information systems. All data are collected at the control center. The T and D system is comprehensively evaluated there in terms of the T and D loss, T and D system reliability, overload operation, total cost, and other parameters. Based on the evaluation, the T and D system is operated optimally. Moreover, the

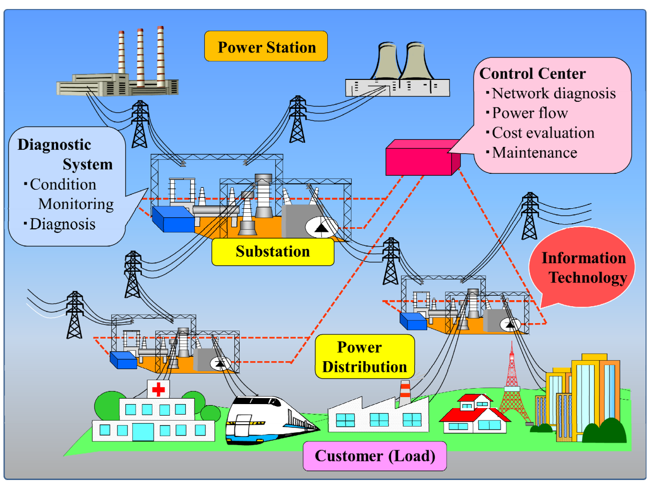


Figure 1. Concept of intelligent grid management system (IGMS).

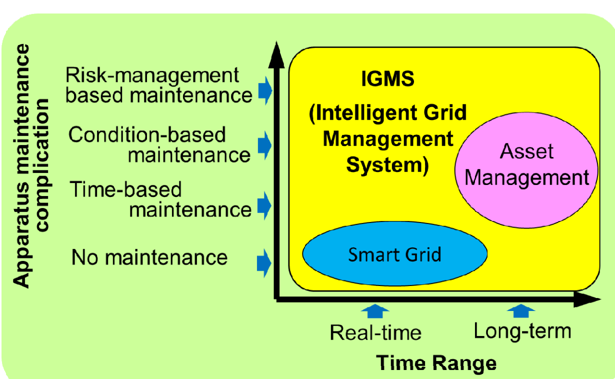


Figure 2. Description of IGMS.

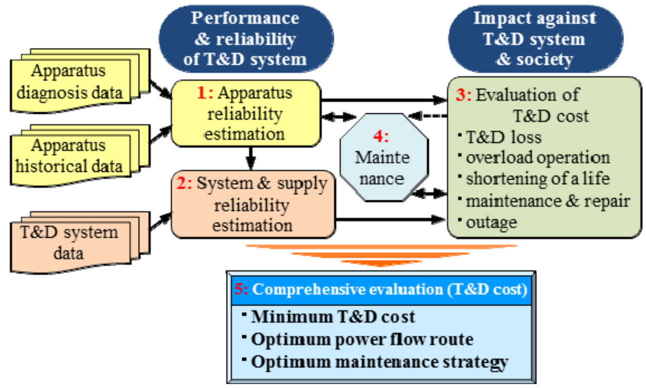


Figure 3. Algorithm for optimization of cost and reliability in IGMS.

maintenance method and schedule of the apparatus are evaluated, and the optimum maintenance strategy is proposed.

An IGMS is the integration of an asset management system and a smart grid, as shown in Figure 2. The horizontal axis shows a time range, and the vertical axis shows the complexity of the maintenance of the apparatus. The asset management system works by using TMB (Time-based maintenance) and CBM (Condition-based maintenance) over the long term. Although asset management takes into account only the degradation of the apparatus, power flow control is not carried out. On the other hand, power flow control does not take into account the degradation of the apparatus as asset management does.

The IGMS can minimize the impact of the individual reliability of an apparatus on the whole insulation system by using power flow control and apparatus maintenance. An important point is that this evaluation converts all events into the cost, which is a concept that is essentially different from that of other systems.

2.2 SIMULATION PROCEDURE

The algorithm of the IGMS is shown in Figure 3. The algorithm consists of the following five basic steps:

(Step 1) **Apparatus reliability estimation**: The current and future reliability and performance of the apparatus are estimated based on the diagnosed results and the apparatus history data [8].

(Step 2) **System and supply reliability estimation**: Failure patterns of the T and D system are calculated chronologically with a sequential Monte Carlo simulation by using T and D system data and the estimated apparatus performance.

(Step 3) **Evaluation of T and D cost**: According to the failure patterns in Step 2, all probable events in the T and D system are evaluated as cost. The sum of all costs (T and D cost) is calculated, and the minimizing conditions are derived.

(Step 4) **Maintenance:** As maintenance improves apparatus performance and reliability, Steps 1–3 are repeated as conceivable maintenance is performed.

(Step 5) **Comprehensive evaluation:** The minimum T and& D cost and corresponding conditions are extracted from all the calculated values obtained in Steps 1–4. The extracted result suggests the optimal maintenance strategy and the optimal T and D power flow routes.

3 SIMULATED T & D SYSTEM MODEL

3.1 OBJECTIVE FUNCTION

The objective function of T and D cost z consists of many cost components. By minimizing z with nonlinear programming, the minimum T and D cost and the optimal T and D route are estimated. The objective function is shown in equation (1).

$$\begin{aligned} \min z = & \sum_{(i,j)\in \text{Line}} a_{ij}(X_{ij}) + \sum_{(i,j)\in \text{OverLine}} b_{ij}(X_{ij}) \\ & + \sum_{m\in \text{OverEquip}} c_m(X_m) + \sum_{n\in \text{OutLoad}} d_n(X_n) \\ & + \sum_{n\in \text{OutLoad}} e_n(X_n) + \sum_{m\in \mathit{Ment}\text{Equip}} f_m(X_m) \\ & + \sum_{k\in \mathit{PowerEquip}} g_k(X_k) + \sum_{m\in \mathit{FailEquip}} h_m(X_m) \end{aligned} \quad (1)$$

where,

z: the objective function of T and D cost
X_{ij}: the transmission power flow from substation SS_i to SS_j
X_m: the electric power flow in apparatus m
X_n: the outage power of load n
a_{ij}: the cost of the T and D loss during normal operation
b_{ij}: the cost of the T and D loss during overload operation
c_m: the damage caused by a shortened service life due to overload operation
d_n: the customer's outage cost
e_n: the supplier's outage cost
f_m: the maintenance cost
g_m: the fuel cost of power apparatus
h_m: the repair cost of failed apparatus
Line: the sets of transmission lines
OverLine: the sets of overload lines
OutLoad: the sets of outage loads
MentEquip: the set of apparatus in the T and D system
FailedEquip: the set of failed apparatus in the T and D system
PowerEquip: the set of power generation apparatus

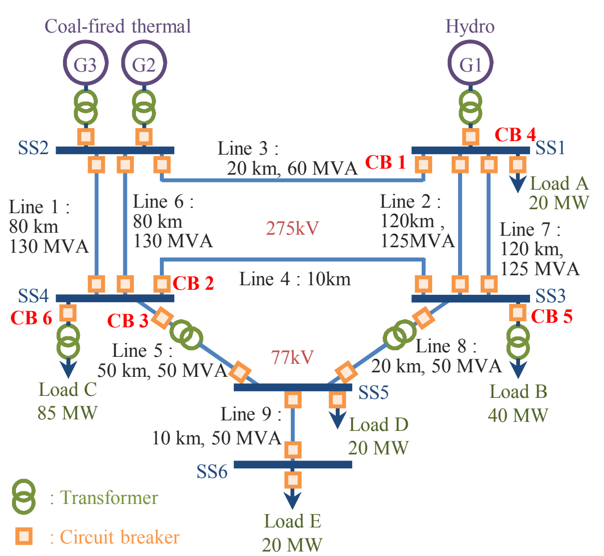


Figure 4. Billinton test system [13].

The customer's outage damage depends on the types of customers [13]. Maintenance cost and apparatus price of references are used [2, 14], and the repair cost of the failed apparatus is assumed to be one-third of the apparatus cost.

In a power transformer, the mechanical strength of the insulation paper is degraded by the temperature rise of oil. Thus, the service life of a transformer (TR) is shortened by overload operation. This shortened service life of a TR from overload operation is estimated according to reference [15].

3.2 T & D SYSTEM MODEL AND TARGET APPARATUS

In Figure 4, a Billinton test system (RBTS) for an evaluated 275 kV / 77 kV T and D system is shown, which contains three power stations and six substations with a total load of 185 MW [13]. The substations are in a double-bus arrangement. RBTS can easily provide the comprehension required in the various steps in modeling, the set of assumptions involved, the algorithmic development, and the calculation process used to evaluate the reliability of the system better than the IEEE reliability test system [16]. The rated capacity and the length of transmission lines are defined.

The circuit breaker (CB) and TR ages in the model are assumed for two conditions, which are a new installed condition and an inhomogeneous aged condition. A new installed condition means that each apparatus is new. An inhomogeneous aged condition means that the manufacturing year of each apparatus is generated at random in a certain country, and the resulting ages are

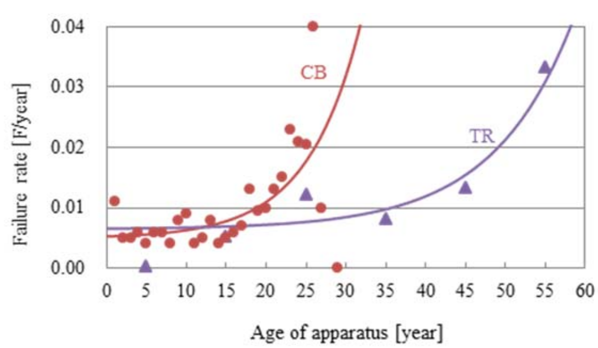


Figure 5. Failure rate of each apparatus [17, 18].

assigned to CBs and TRs. Literature data were used for the failure rate of the CB [17] and TR [18], as shown in Figure 5, instead of the diagnosed ones for simplification of calculations. The failure rate excepting the target apparatus was assumed constant, as listed in Table 1 [17–19].

Table 1. Failure rate of other target apparatus [17-19].

Equipment	Failure rate [F/yesr]
TR	0.0066
CB	0.0053
Line	0.0150

4 POWER FLOW CONTROL STRATEGY OF IGMS

4.1 POWER FLOW CALCULATION

It is important to stabilize voltage while operating an electric power system. Therefore, the total difference between the actual voltage and the rated voltage added to each line was used in the control function $F_{control}$. The voltage phase difference between the power generation plant, change of a tap with a transformer, and on-off of each switch were controlled to minimize this control function. As a result, the best voltage in each node and electric energy flow in a system were acquired. Control function $F_{control}$ is shown in equation 2.

$$F_{control} = \sum_{(i,j)\in Line} A_{(i,j)} \cdot \left(\frac{V_{(i,j)} - V_{n(i,j)}}{V_{n(i,j)}} \right)^2 \qquad (2)$$

where,

$F_{control}$: the control function

Line: the set of all lines

$A_{(i,j)}$: the importance of the line between substation SS_i and SS_j

$V_{(i,j)}$: the voltage of the line between substation SS_i and SS_j

$V_{n(i,j)}$: the rated voltage of the line between substation SS_i and SS_j

In this calculation, importance $A_{(i,j)}$ yielded a value proportional to the amount of power failure damage in the directly connected load.

The electric power generated in the power plant is sent to consumers through power lines and transformers. In that case, the losses from electrical resistance in a power line, in a transformer winding, and by hysteresis of the core in a transformer occur. If three phases of voltage are balanced, electric power losses P_{Line} from the resistance of a power line are decided by resistance R and load current I of power lines.

The transformer was considered as an apparatus with a decreasing life. In the considered transformer, it was assumed that the temperature increased to 40 ºC when the load factor increased to 100%. When an additional temperature rise of 7 ºC occurred, the lifetime of the solid insulator was decreased by half, which is described by the general degradation characteristics. On the other hand, in this calculation, the life decrease of the apparatus is estimated as the cost from an increase in breakdown probability and increase in the depreciation expense.

The power failure damage of a consumer changes with importance, such as the industry of the consumer. Thus, the average value of the power failure damage was used.

4.2 POWER FLOW OPTIMIZATION OF NEW INSTALLED NETWORK

The optimal power flow control in the case when all electric power apparatus in Figure 4 are in a newly installed condition is considered. The failure rate of the apparatus in this case was assumed constant, as listed in Table 1. In power flow control, the switches of both the ends of a power line are operated by various patterns. All connecting patterns are numbered, and the typical patterns are shown in Table 2.

Pattern 32 minimizes the T and D loss because there is high reactive power flow in Line 3 with 65.4 MVA in Pattern 0, when all the lines are connected as shown in Figure 6. In this case, the entire cost is comparatively low and Pattern 32 turned out to be the optimal power flow control.

The power flow was calculated for each control pattern. Moreover, in the power flow of each control pattern, all the

Table 2. Compendium of control patterns.

Control Pattern number	G1 - G3	Line									Load A - E
		1	2	3	4	5	6	7	8	9	
0	All ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	All ON
8	All ON	OFF	ON	ON	ON	ON	ON	ON	ON	ON	All ON
32	All ON	ON	ON	OFF	ON	ON	ON	ON	ON	ON	All ON
40	All ON	OFF	ON	OFF	ON	ON	ON	ON	ON	ON	All ON
64	All ON	ON	ON	ON	OFF	ON	ON	ON	ON	ON	All ON
96	All ON	ON	ON	OFF	OFF	ON	ON	ON	ON	ON	All ON
128	All ON	ON	ON	ON	ON	OFF	ON	ON	ON	ON	All ON
160	All ON	ON	ON	OFF	ON	OFF	ON	ON	ON	ON	All ON
192	All ON	ON	ON	ON	OFF	OFF	ON	ON	ON	ON	All ON
200	All ON	OFF	ON	ON	OFF	OFF	ON	ON	ON	ON	All ON
1152	All ON	ON	ON	ON	ON	OFF	ON	ON	OFF	ON	All ON
2048	All ON	ON	ON	ON	ON	ON	ON	ON	ON	OFF	All ON
ON-OFF Pattern	1, 2, 3 ,	4 ,	5 ,	6 ,	7 ,	8 ,	9 ,	10 ,	11 ,	12 ,	13-17

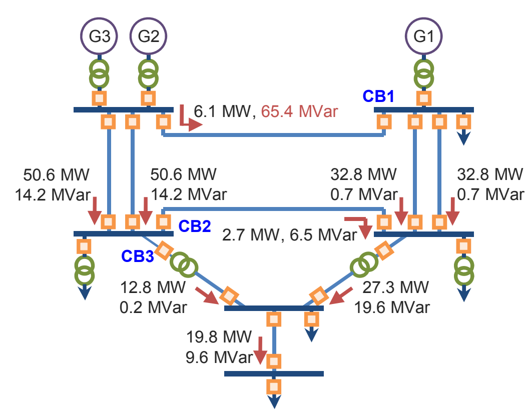
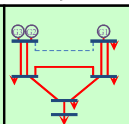
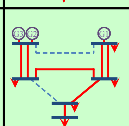
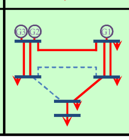


Figure 6. Power flow pattern.

Table 3. Apparatus diagnosis and failure rate.

Time		(a) ~ 0 hour	(b) 0 ~ 14 hour	(c) 14 hour ~
CB 1	Diagnosis result	Normal state	Normal state	Normal state
	Failure rate [F/year]	0.0053	0.0053	0.0053
CB 2	Diagnosis result	Normal state	Normal state	Abnormal state
	Failure rate [F/year]	0.0053	0.0053	0.50
CB 3	Diagnosis result	Normal state	Abnormal state	Abnormal state
	Failure rate [F/year]	0.0053	0.50	0.50

Table 4. Power flow control pattern and total cost of the new installed network.

—— : ON ----- : OFF		(a) -0 hour	(b) 0-14 hour	(c) 14- hour
Pattern 32		**36.2 (minimum)**	41.5	46.9
Pattern 160		38.0	**38.0 (minimum)**	43.4
Pattern 192		38.8	38.8	**38.8 (minimum)**

Total cost [k¥ / h, 10*US$/h]

phenomena that may occur in electric power systems, such as T and D loss and equipment failure, are converted into cost. The control that has the minimum cost among all the control patterns is judged as optimal. Condition monitoring of the apparatus, such as the partial discharge diagnosis and control current diagnosis, is performed every hour for each circuit breaker (CB 1 to CB 3) in the system of Figure 4, and power flow control is applied according to the diagnostic results.

The diagnosis result and optimum power flow control at each time are summarized and shown in Tables 3 and 4.

Before a certain time (here, we define this time as 0 h), it was diagnosed that the state of each CB was normal. Thus, the failure rate of each CB was small, that is, 0.0053 F/year, as shown in Table 3. In that case, the control (Pattern 32 in Table 4) that can minimize the T & D loss becomes the optimum control.

It is assumed that the UHF sensor operating online detects a partial discharge in CB 3 at 0 h and displays an alarm for an abnormal state [20]. If a failure such as a grounding accident occurs in CB 3, it is necessary to turn off all CBs surrounding CB 3 for a certain time. There is a possibility that the influence of an accident may affect the entire system. Because the failure risk of CB 3 became large in this state, the total cost increased, and Pattern 32 was no longer optimal. Then, the control turned off CB 3 and separated Line 5. By changing to Pattern 160, the cost of the sum total by failure without CB 3 decreased. As a result, although some T and D losses increase as compared with the first state, because an accident involving the entire system can be prevented, the total cost is maintained at the minimum with optimal power flow.

Furthermore, time marches on, and at the 14th h, it is assumed that abnormalities are found in the control current of CB 2. It is diagnosed that the failure rate of CB 2 rises to 0.50 F/year at this time. In that case, the total cost is minimized by changing to Pattern 192, which turns Line 3 on and Line 4 off.

4.3 POWER FLOW OPTIMIZATION OF INHOMOGENEOUS AGED NETWORK

The case of an inhomogeneous aged network, as shown in Figure 7, is considered. In this case, Line 1 has a highly aged deterioration state of 55 years, and the average years of deterioration of the apparatus are approximately 20.

In this case, Pattern 40, as shown in Table 2, turned out to be the optimal power flow control. This pattern serves as a control that avoids the damage accompanying failure by turning Line 1 off that has apparatus with a high failure rate while turning Line 3 off.

The effect of this control is shown in Table 5. However, the failure rate of the CB in the Line 1 connection is large,

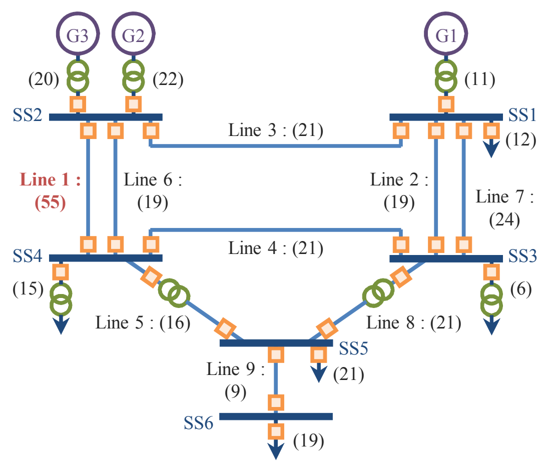
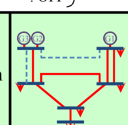
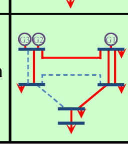


Figure 7. Apparatus condition age of inhomogeneous aged network.

Table 5. Power flow control pattern and total cost of inhomogeneous aged network.

—— : ON ----- : OFF		(a) -0 hour	(b) 0-14 hour	(c) 14- hour
Pattern 40		**44.7 (minimum)**	50.1	55.4
Pattern 200		47.4	**47.4 (minimum)**	**47.4 (minimum)**

Total cost [k¥ / h, 10*US$/h]

and the failure damage cost is increased. For this reason, in the control using Line 1, the influence of failure and the total cost will increase. If the control method is changed to Pattern 40, although some T and D losses increase, the failure damage cost can be reduced greatly, and the total cost can be minimized.

With the same case study of the power flow optimization with a new network, before a certain time (here, we define this time as 0 h), it was diagnosed that the state of each CB was normal. In this case, Pattern 40 is optimal.

It is assumed that the UHF sensor operating online detects a partial discharge in CB 3 at 0 h and displays an alarm as the abnormal state. Because the failure risk of CB 3 increases, the total cost rises and Pattern 40 is no longer the optimal pattern. Then, the control separates Line 4 and Line 5 and turns Line 3 on. By changing to Pattern 200, the cost of the sum total by failure without CB 3 is minimized.

Furthermore, at the 14th hour, it is assumed that abnormalities are found in CB 2. Additionally, in this case, the total cost is minimized by Pattern 200.

By using the IGMS as mentioned above, the power system that has a deterioration apparatus can be controlled by a method that reduces not only the cost of T & D losses but also the damage cost due to apparatus failure.

5 MAINTENANCE STRATEGY OF IGMS

5.1 APPARATUS FAILURE RATE AND MAINTENANCE COST-EFFECTIVENESS

To estimate the optimum maintenance strategy, the IGMS can analyze the T & D cost for all combinations of three maintenance methods (regular maintenance: RM, overhaul: OH, and replace: RP) for all apparatus. Figure 8 shows the maintenance effect. CBs are tested annually for ordinary conditions by RM. The arcing chamber of a CB is exchanged in the OH, and half of the CB is replaced. The RM cost, OH cost and RP cost are assumed to be 0.8%, 20%, and 100% of the apparatus price, respectively. However, such calculation requires large amounts of computing time. For simplification of calculation in this paper, three CBs with high failure costs were selected for evaluating the optimum method and timing for maintenance. Literature data were used for the failure rate of the CB [20], as shown in Figure 5, instead of the diagnosed ones for simplification of calculations. In this paper, the maintenance strategy plan was calculated for two cases. One case is that all apparatus are newly installed as in Section 4.2, and the other case is that the apparatus are aging with the distribution shown in Figure 7. The failure rate excepting the target apparatus was assumed constant, as listed in Table 1.

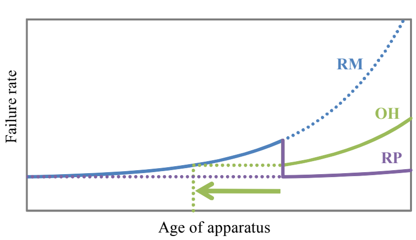


Figure 8. Maintenance effect.

To obtain the optimum maintenance strategy, the evaluation period was designated. In this paper, the evaluation period was fixed at 60 years, which was considered to be sufficient for the average life span of the electrical apparatus.

All of the possible maintenance plans for the evaluation period were extracted by an exhaustive search. Then, for each maintenance plan, the total T and D costs in the evaluation period were calculated. To calculate the total T & D costs of all the possible combinations of three maintenance methods, the timing of the maintenance and determining which apparatus to apply maintenance during the evaluation period are required. By comparison of the total T & D costs of each maintenance plan, the optimum maintenance plan that minimizes the total T and D cost was derived. However, such calculation requires an enormous amount of time. Therefore, to simplify the calculation, the interval between calculations was fixed at three years. The optimum maintenance plans of selected CBs (CB4, CB5, and CB6) that were connected to different load capacities (Load A: 20 MVA, Load B: 40 MVA, Load C: 85 MVA) were derived, and optimum maintenance plans were evaluated.

5.2 OPTIMUM MAINTENANCE PLANS OF CBS IN NEW INSTALLED NETWORK

In this case, all apparatus that include the target apparatus in the model are newly installed, so the number of aged years is zero at first. The details of each plan and the transitions of the cumulative cost are shown in Figure 9 and Table 6. It is found that the optimum maintenance plans vary among different load capacities. In the case of CB5 connected to a 40-MW load, the timing of the OH and RP are shifted to three years shorter than those of CB4. This is attributed to the outage size induced by the CB failure. Because CB failure results in the outage directly, the larger load requires a higher priority for the reliability.

When CB6 is connected to the largest load of 85 MW, it requires exceedingly higher reliability; hence, early replacement is required. Thus, the optimum maintenance plan of CB6 was determined to apply RP twice at the 21st and 41st year, respectively. Despite carrying out RP twice during the evaluation period, the total T and D cost is reduced as compared with the TBM, which applied RP only once.

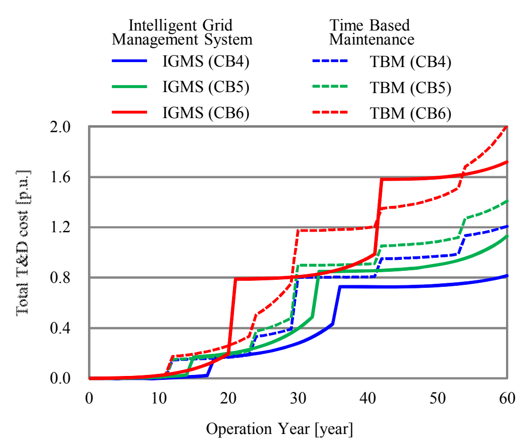


Figure 9. Comparison of transitions of the cumulative cost with new CBs.

Table 6. Power flow control pattern and total cost with new CBs.

Maintenance Method	Start Age [Year]	Target Equipment	Load Capacity [MW]	Maintenance Timing [year]		Cost Reduction to TMB [%]
				OH	RP	
IGMS	0	CB4	20	18	36	32.6
	0	CB5	40	15	33	19.9
	0	CB6	85	-	21, 42	14.4
TBM	0	CB4	20	12, 24 42, 54	30	-
	0	CB5	40	12, 24 42, 54	30	-
	0	CB6	85	12, 24 42, 54	30	-

5.3 OPTIMUM MAINTENANCE PLANS OF CBS IN INHOMOGENEOUS AGED NETWORK

In this case, there was an average of 20 years of aging, as shown in Figure 7. The maintenance of CB4, CB5, and CB6 was also optimized. These results are shown in Figure 10 and Table 7.

Because there are many old apparatus as compared with all the newly installed apparatus, as shown in Figure 8, the number of OHs is increased. On the other hand, CB6 has the longest aging in three CBs at the start time of the IGMS. Though the aging of CB6 is 15 years, which is half of the design life, this aging does not affect the number of RP. Because the number of OHs and the breakdown probability increase the apparatus ages, in both TBM and IGMS, the costs of an aging system are approximately 20% higher than that of a newly installed system.

At the 60th year, the cost of the IGMS is lower than the cost of the TBM, whether the average age is zero or 20

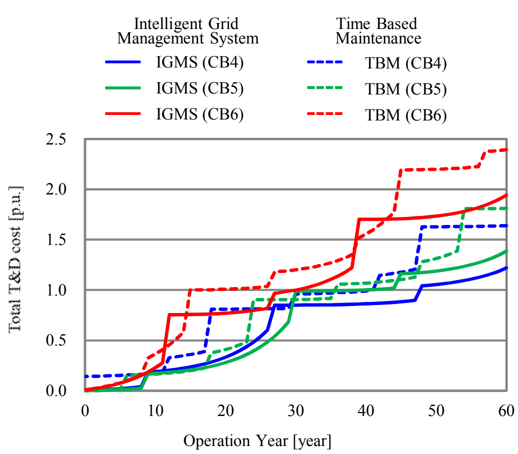


Figure 10. Comparison of transitions of the cumulative cost with inhomogeneous aged CBs.

years. This is the result of calculating so that the cost at the 60th year of operation of the IGMS shall become the minimum because the evaluation period was considered to be 60 years. For this reason, in the intermediate stage by the 60th year, a situation where the cost of TBM becomes cheaper than that of IGMS also exists. This state occurred

Table 7. Power flow control pattern and total cost with inhomogeneous aged CBs.

Maintenance Method	Start Age [Year]	Target Equipment	Load Capacity [MW]	Maintenance Timing [year]		Cost Reduction to TMB [%]
				OH	RP	
IGMS	12	CB4	20	9, 48	27	25.6
	6	CB5	40	9, 45	29	23.4
	15	CB6	85	27	12, 39	18.8
TBM	12	CB4	20	0, 12 30, 42	18, 48	-
	6	CB5	40	6, 18 36, 48	24, 54	-
	15	CB6	85	9, 27 39, 57	15, 45	-

when replacement was carried out. Because the amount of money of replacement each time is large, even if IGMS is applied, it is thought that the cost of IGMS is higher than that of TBM temporarily.

By comparison with TBM, the total T and D costs with IGMS are reduced by optimum plans in any case; hence, the effectiveness of IGMS is verified. From those results, it is ascertained that the IGMS can derive the optimum maintenance plan with consideration of the priority of reliability that is attributed to the outage scale induced by the CB fault.

6 CONCLUSION

The essential problem for the operation and control of power T and D systems is to search for the optimum balance between cost efficiency and quality of a power supply. In order to find a solution to this problem, the authors have proposed the IGMS. In the IGMS, all events in the T and D system were evaluated as T and D costs in many aspects, such as failure, T and D loss, life estimation of apparatus, outage, repair, and maintenance, and the optimum maintenance strategies and optimum power flow route were predicted by minimizing the entire T and D cost. The IGMS can minimize the impact of the individual reliability of an apparatus on the whole insulation system by using power flow control and apparatus maintenance. The IGMS contains the concept of both a smart grid and an asset management system.

In this paper, the IGMS was applied to derive a suitable real-time power flow control based on condition monitoring and the diagnosis results of apparatus. In addition, to consider the apparatus with many components such as a “smart grid,” an optimum maintenance strategy was derived. The IGMS was applied to derive the maintenance strategy of the CBs, and the effective results were indicated. The IGMS can actually determine the appropriate frequency of maintenance and reduce the T and D total cost. The optimum maintenance strategy of the IGMS can reduce the T and D loss and the maintenance cost more than TBM. As the result, the IGMS has the potential to be developed into a more effective tool for future T and D systems.

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