CASE STUDY OF THE DISTRIBUTION SYSTEM PLANNING FOR A MULTI-DIVIDED AND MULTI-CONNECTED SYSTEM

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ABSTRACT

Japan's current distribution system adopts the multi-divided and multi-connected system, which contributes to its high supply reliability. The system reduces the power outage time per household because it can minimize the power outage area when a distribution line accident or construction occurs.

In order to design the distribution system for the multi-divided and multi-connected system, it is necessary to divide the distribution line load equally. Furthermore, a decision on the most suitable setting location for switches in order to minimize power line loss is necessary. However, certain know-how as a grid operator is necessary in the planning. In addition, building a system that effects optimization of the entire distribution system, and which spreads to the whole area, also requires a great deal of time.

In this paper, we will evaluate the effectiveness of the multi-divided and multi-connected system from the viewpoints of investment and reliability. We will also introduce the system construction method and Case Studies.

INTRODUCTION

Japan's distribution system is installed in a net shape in order to supply widely-dispersed customers. In order to ensure high supply reliability, the distribution line is divided into a plurality of sections by a switchgear, and each section is connected to another distribution line via a normally open interlock switch. This distribution system is called the multi-divided and multi-connected system, and it is adopted by each electric power company in Japan. For example, in the triple divided system, the distribution line is divided into three sections by a section switch, and each divided section is connected to three other distribution lines via a connection switch. This makes it possible to freely configure the system by selecting a normally open switch.

In Japan, distribution networks are constructed so that distribution facilities can be networked with interconnection lines to minimize power interruptions during construction and accidents at distribution facilities. Regarding distribution system planning, TEPCO has implemented the optimal selection and arrangement of distribution facilities such as section switches and transformers based on the load demand forecasting knowledge that it has cultivated so far.

In addition, standardization of business operations such as switching procedures for distribution lines and restoration methods in an accident have been introduced, along with distribution facility management and distribution automation.

Furthermore, by incorporating policies concerning facility formation, such as facility operation rate concept and facility use conditions, every year, we supervise execution by weighting the budget allocation, while responding to changes in regional characteristics such as climate and demand density. This has realized high supply reliability globally while building facilities that can respond to demand growth.

Figure 1 compares the annual duration of outages per household (System Average Interruption Duration Index: SAIDI) in major countries. As shown in the figure, Japan has a high degree of reliability compared with other countries, at 20 minutes a year, but TEPCO realizes an even higher reliability of 4 minutes a year.

In a distribution system where a loop system and radial system are mixed in one emerging country state, a distribution plan for a multi-divided and multi-connected system was created for the purpose of improving supply reliability. The area in question currently has a high SAIDI, and contains many factories and so on. It is a region where high reliability is demanded and future demand increase is expected.

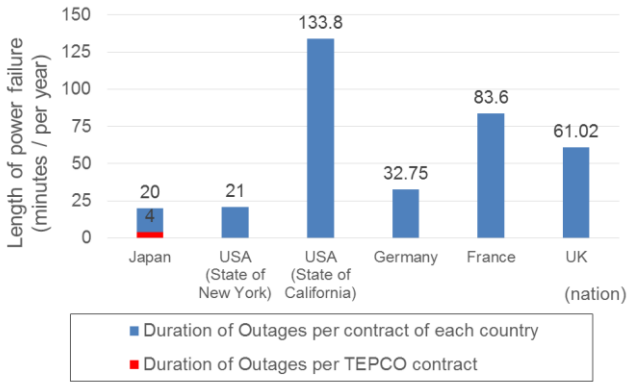

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Fig. 1 International comparison of outage duration

OUTLINE OF MULTI-DIVIDED AND MULTI-CONNECTED SYSTEM

Figure 2 shows a schematic diagram of a multi-divided and multi-connected system. One distribution line is divided into three by a section switch (■), and each section is connected to another distribution line by a normally open interlock switch (□). In addition to switches that divide sections, several switches (●) are sometimes installed between section switches for the purpose of reducing the power interruption area caused by distribution line accidents or construction work.

Table 1 shows a comparison of the multi-divided and multi-connected system and other general distribution systems. As shown in the table, the radial system can operate the distribution line with a high distribution line operation rate, but since the distribution lines are not connected, the supply reliability becomes low.

In the multi-divided and multi-connected system, the section is divided into multiple sections, and each divided section is interconnected, thereby maintaining a high supply reliability equivalent to that of the loop system and realizing a high operation rate.

In the case where the section is divided into three sections, the operation rate of the distribution line is 75% as shown in formula (1), and in a region where demand is expected to increase compared with the loop system, the chance of newly establishing a distribution line decreases. Therefore, as shown in Figure 3, it is possible to defer the establishment of new distribution lines, and investment can be suppressed.

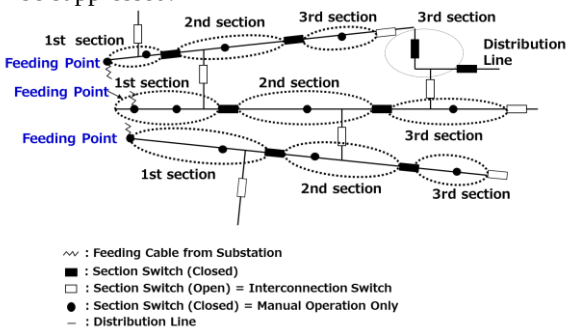
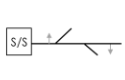
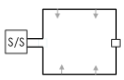
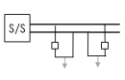
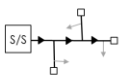


Fig. 2 Schematic diagram of a multi-divided and multi-connected system

Table 1. Comparison of distribution systems

*1 Assumption: feeder is divided into three parts, *2 CAPEX: Capital Expenditure

	Radial	Loop (Ring)	Primary selective	Multi-divided and multi-connected
MV system				
Maximum outage part	Whole	Half	None	33% ($\frac{1}{N}$)*1
Maximum operation rate	100%	50%	50%	75% ($\frac{N}{N+1}$)*1
Reliability	Lowest	High	High	High
CAPEX*2	Lowest	High	Highest	Low
Remarks	• Mainly adopted in developing countries • Lowest cost	• Mainly adopted in western countries • Easy operation in case of load transfer	• Mainly adopted in important facilities • Highest cost	• Adopted in Japan • Load management skill is required

$$\text{Operation rate} = \frac{Divided\ number}{Divided\ number + 1} \times 100(\%) \qquad (1)$$

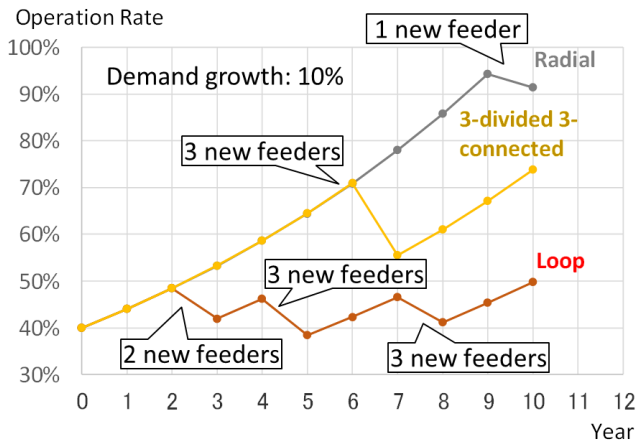


Fig. 3 Simulation of the establishment of distribution lines

Figure 4 shows a comparison of SAIDI for a radial system and multi-divided and multi-connected system. Here, it is assumed that a distribution line accident occurs in the second section. In the radial system, all of the power distribution lines are out of power, but in a multi-divided and multi-connected system, the switches at both ends of the power interruption section are opened, and the accident sections can be separated from the healthy section, thereby avoiding power outage of the entire distribution line. With regard to healthy places in the 1st and 3rd sections, it is possible to supply electricity from the substation for the 1st section and, for the 3rd section, which is on the load side from the accident section, from another distribution line by inserting an interconnection switch. In this way, SAIDI can be reduced to approximately 1/3 as shown in the figure.

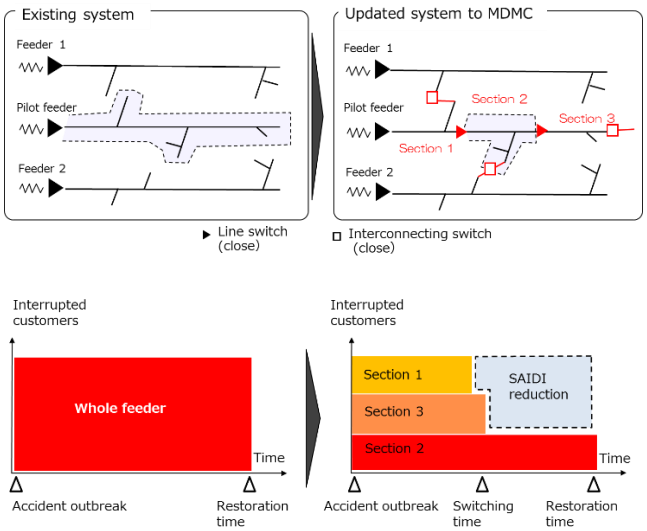


Fig. 4 Comparison of SAIDI in distribution systems

SUPPORT SOFTWARE FOR DISTRIBUTION SYSTEM PLANNING

In order to introduce a new multi-divided and multi-connected system in emerging countries, we used distribution planning support software called Decision-making Support Software (DSS, developed by Hitachi, Ltd.). This is specialized software for a multi-divided and multi-connected system and it is widely used in Japan.

DSS has a function specifically for multi-divided and multi-connected system configuration that maintains high reliability in the Japanese distribution system compared with the distribution system analysis software used in Western countries.

Table 2 shows a functional comparison with typical distribution system analysis software. In addition to system analysis and load management functions, DSS, like other software (CYME, developed in Canada), also has functions such as a section optimum switch arrangement for examining the distribution system of the multi-divided and multi-connected system, and a work procedure creation function for distribution line power outages.

Figure 4 is an example of an analysis results screen for the optimum switch arrangement.

For distribution system planning, it is possible to consistently carry out operations such as planning based on enormous equipment information, and facility management, by using DSS. Standard manipulation of distribution planning work is performed via data processing algorithms in the software rather than conventional manpower work, improving accuracy and achieving remarkable labor saving results.

In addition, DSS has been used for about 30 years in 70% of electric power companies in Japan.

Table 2. Functional comparison of analysis systems

Function	DSS	CYME
System analysis	✓	✓
System optimization	✓	✓
Optimal arrangement of facilities	✓	
Work procedure creation	✓	
Load management	✓	✓
System maintenance	✓	
System diagram display	✓	✓

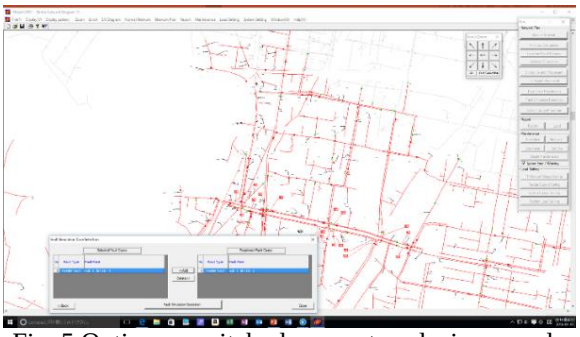


Fig. 5 Optimum switch placement analysis example screen

PROCEDURE FOR DISTRIBUTION SYSTEM PLANNING

Figure 6 shows the procedure for creating a distribution system plan. In order to construct a new distribution system, we decided to carry out the following procedure.

Step 1: Ascertainment and evaluation of problems in existing distribution system using DSS

Step 2: Planning of countermeasures for problems by TEPCO staff

Step 3: Evaluation of countermeasures using DSS

Step 4: System optimization based on analysis results

Step 5: Updating of distribution line based on demand forecast

As shown on the right side of the figure, in step 3, by implementing the optimum arrangement of switches, which is a characteristic function of DSS, running accident simulations, and using the loss mini function, an efficient and labor saving system can be designed.

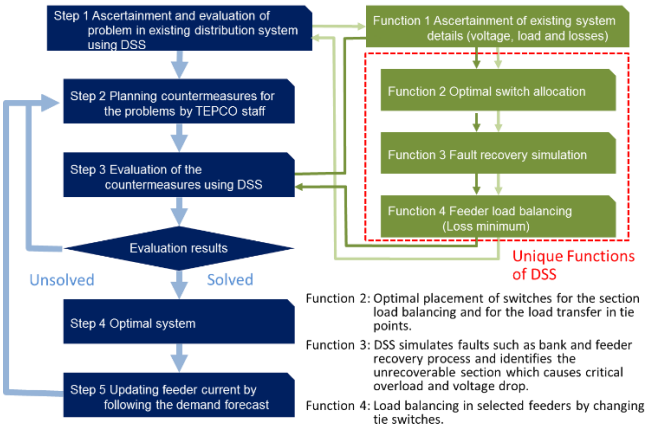


Fig. 6 Procedure for distribution system planning

EXAMPLE OF THE APPLICATION OF MULTI-DIVIDED AND MULTI-CONNECTED SYSTEM

For this case, the regions of emerging countries that use a multi-divided and multi-connected system in demonstration projects have a population of 230,000 and are supplied by two distribution substations with a total of 16 distribution lines.

Figure 7 shows an existing distribution system diagram. The target distribution lines were two of distribution substation A and four of distribution substation B.

In this area, load demands from facilities such as factories are high and high reliability is required. As can be seen from the figure, several interconnection switches are installed and some loop systems are adopted.

However, in this area, the demand for load is increasing by around 10% per year, and it is expected that the establishment of distribution lines in the current distribution system will be essential, with enormous investment required accordingly.

Figure 8 shows the operation rate for each distribution line

predicted based on the existing operation rate, with load demand set at 10% per year. There are two distribution lines whose operation rate already exceeds 50%. Also, in three years' time, more than half of the distribution lines will be over 50%, and countermeasures requiring investment, such as the establishment of distribution lines, are necessary to operate in a loop system. As shown in Table 1, if the system configuration of a three divided and three connected system is present, the operation rate will be raised to 75%. Therefore, it becomes unnecessary to install a new distribution line for at least three years, and investment similarly becomes unnecessary.

Although an interconnection switch is installed in the existing distribution line in Figure 7, a section with switchgear is not planned, so it is impossible to minimize the power interruption area at the time of a distribution line accident or during construction, and as a result SAIDI is a very high value.

In this area, with the use of DSS and our company's distribution planning expertise, we designed a multi-divided and multi-connected system.

Figure 9 shows a three divided and three connected system composed of optimal switch layouts considering the current load distribution and minimum loss.

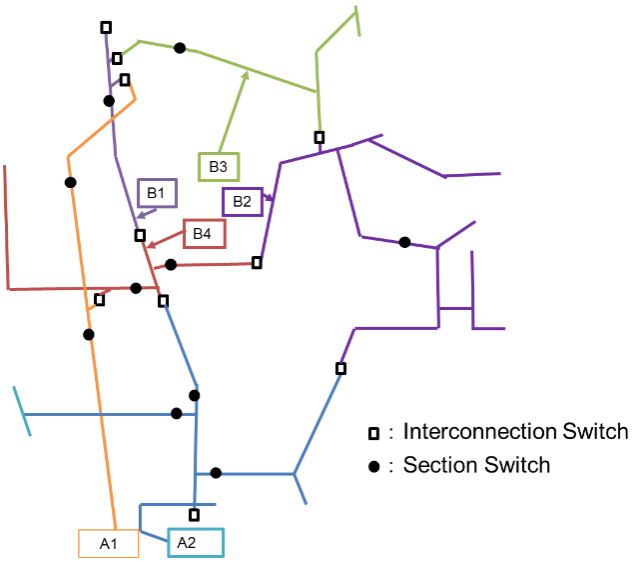


Fig. 7 Existing distribution system

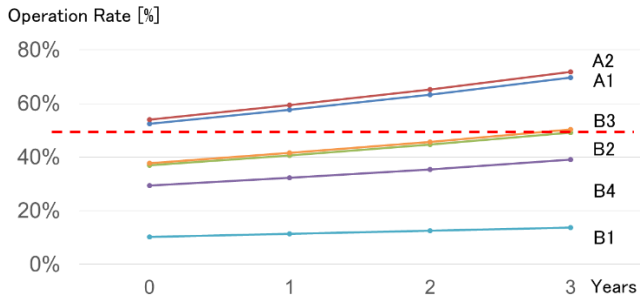


Fig. 8 Operation rate forecast for each distribution line

In addition to the establishment of section switchgear, the construction of new distribution connecting lines and the establishment of connection points, the structure of a three divided and three connected system was adopted. Since interconnection switchgear is already installed in this area, by making full use of the existing switchgear the number of newly installed switches is set to six at four places.

However, in the part where the load of the distribution line is small, from the viewpoint of optimizing investment it is divided into two, and the system is changed according to the load demand. As described above, one of the features of a multi-divided and multi-connected system is that it can have a flexible system configuration to correspond to future load demand. We have already received construction permission to change the system configuration at the site and are making changes via early construction.

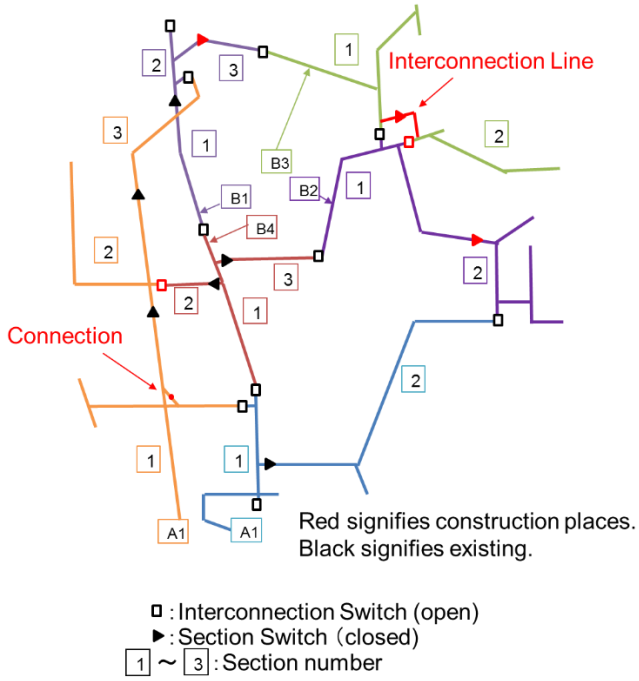


Fig. 9 Three divided and three connected system based on DSS results

EVALUATION OF MULTI-DIVIDED AND MULTI-CONNECTED SYSTEM

In order to evaluate the multi-divided and multi-connected system, the procedure for a distribution line accident until power outage recovery in the existing system was broken down, and the respective times were compared.

Table 3 compares the power outage times in the existing system with those constructed. The accident is at distribution line B2 in Figure 7, an outage due to insulator breakage. In this accident, it takes 85 minutes until power recovery. Although the time breakdown was not recorded at the time, an interview was conducted with the manager in charge of the operation, who confirmed the time taken

from the accident point discovery to the repair, including the substation CB operation.
Since the distribution line is divided into three and three connected, it is possible to transmit a section other than the accident part from another distribution line, so the patrol time required to find accident points is reduced to approximately 1/3. Due to this, the total power outage time becomes 63 minutes, about 3/4 of that before the three divided and three connected system. In this way, the multi-divided and multi-connected system can be expected to reduce the time required to find the accident point by minimizing the accident section.
With regard to the SAIDI reduction effect, since the system is divided into multiple parts, it is possible to restore the healthy section without accidents ahead of time, so the SAIDI reduction effect of ①shown in Figure 10 can be expected.
In addition to the above, in the existing system constructed this time, the portion ② in Figure 10, which is the time reduction effect for the patrol to find the accident point as described above, is expected as the SAIDI reduction effect. As a whole, since the interruptions in ①and ②are reduced, SAIDI is expected to improve by approximately 50%.

Table 3. Reduction of patrol time for finding accident points

Units: minutes

	Current	Proposed
Total outage duration	85 - 25%	63
Reclose CB	10	10
Arrive at site	10	10
Testing charging	- -66%	5
Patrol	40	13
Repair work	20	20
Restoration	5	5

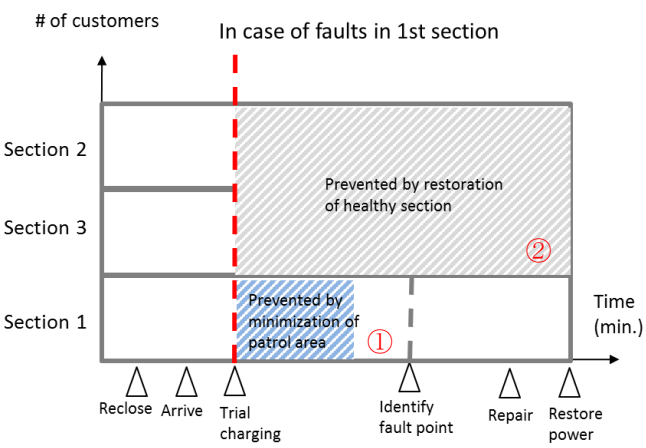


Fig. 10 SAIDI reduction effect

Regarding capital expenditure, as shown in Figure 11, we compare how the investment amount changes with increasing demand according to the distribution system scheme in the area where the system configuration was changed. The load demand is calculated assuming that there is an increase of 10% per year.
Regarding the multi-divided and multi-connected system constructed in this case, although initial investment such as that for establishing a switch for section division is necessary, after 3 years the investment amount for a conventional loop system will exceed this. With a multi-divided and multi-connected system, investment for new distribution lines will be necessary as future demand increases, but the investment can be deferred. In addition, since the initial investment can be a system configuration that takes advantage of the existing switchgear and minimum loss using DSS, as in this case, it can be said that the multi-divided and multi-connected system is an effective distribution system for areas where load demand is expected to increase.

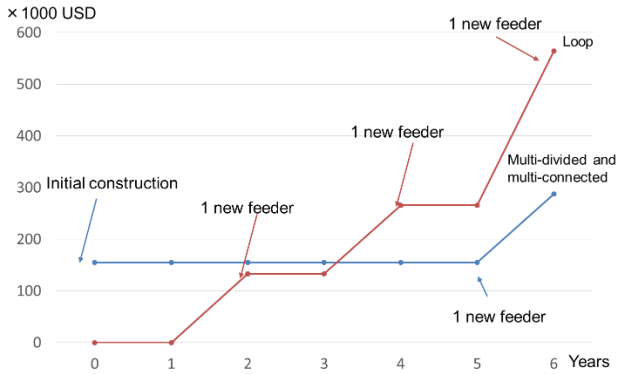


Fig. 11 Comparison of investment for each distribution system

CONCLUSION

In this paper, the multi-divided and multi-connected system adopted in Japan was compared with other distribution systems and the advantages were described. In addition, as demand is expected to increase, it was shown to be economically superior to a conventional system such as a loop system.
We introduced this system as a pilot in areas where emerging countries' demand is expected to increase. Although voltage classes were different from those in Japan, we were able to create an effective system plan in a short time by utilizing distribution system planning and specialized software that we have cultivated.
In the future, we plan to carry out construction according to the plan and evaluate the effect actually obtained, such as improvement of reliability etc., by multi-divided and multi-connected system operation.