10691 Session 2022
B1
PS2: FUTURE FUNCTIONALITIES AND APPLICATIONS.

A Study of Quality Management System for Underground Transmission Lines by Japanese Transmission System Operators

Takato WATANABE＊
Chubu Electric Power Grid Co., Inc.
Watanabe.Takato@chuden.co.jp
Yutaka TSUJI
TEPCO Power Grid, Inc.
tsuji.yutaka@tepco.co.jp
Masataka OGURA
Kansai Transmission and Distribution, Inc.
ogura.masataka@e3.kansai-td.co.jp
Japan

SUMMARY

The underground transmission lines are composed of cables manufactured at the factory and the joint box, which is assembled on site. Electrical breakdowns are mainly caused by the deterioration of cable insulation, production defects or the poor assembly of joint boxes.
Japanese transmission system operators (TSOs) establish their own quality management system (QMS) in addition to ISO 9001 or other national/internatinal standard, in which they continuously maintain and improve the quality of our transmission lines.
Authors surveyed the number of XLPE cable faults that occurred in Japan and compared it with global failure statistics to verify the effects of the QMS.
The breakdown rate in Japan in 66 kV XLPE cables is reported to be about 0.05[/100 km.cct.year]. In contrast, the global breakdown rate in 60-109 kV XLPE cables is reported by CIGRE to be about 0.0939[/100 km.year]. Authors consider why the dielectric breakdown rate is lower in Japan and attribute the difference to the implementation of the QMS.
An important feature of the QMS is a scheme for continuous improvement. At each stage of design, manufacturing, construction and operation, engineers and maintenance staff in each responsible organization are encouraged to propose improvements, which are then reflected in the company rules. QMS ensures that all engineers and maintenance staff can carry out the Plan-Do-Check-Action (PDCA) cycle.
The contents of QMS for underground transmission lines by TSOs can be categorized into four stages, "Design", "Manufacturing", "Construction" and "Operation".
In design stage, the required performance and test methods for cables and joints are not entirely left to manufacturers. TSOs determine the specifications in cooperation with manufacturers, reflecting knowledge obtained from experiences. In manufacturing stage, one of the characteristics is that several TSOs in Japan adopt “a type approval system”. In this system, TSOs determine the specification of frequently used products on their own, check their performance in advance, and approve products if they pass the required test.
In construction stage, the certification system for local construction companies has been established by each TSO. This system is adopted in some voltage classes where construction companies contract to assemble the cable accessories, and their workers who passed the qualification tests can engage in the cable jointing work.
In operation stage, TSOs establish the standards of maintenance and specific measures in preparation for malfunctions and breakdowns of underground transmission line. They possess spare cables and joints for the purpose of early restoration. In addition, some TSOs have their own jointers. In some cases, TSOs are trying to prevent failures by continuously monitoring the conditions of joints online.

From the above, it can be said that the QMS largely contributes to the low failure rate of underground transmission lines in Japan.
When a fault occurs, the cause is thoroughly investigated, and measures to prevent recurrence are shared among TSOs. These efforts also have led to improvements in the quality of underground transmission lines in Japan.

KEYWORDS

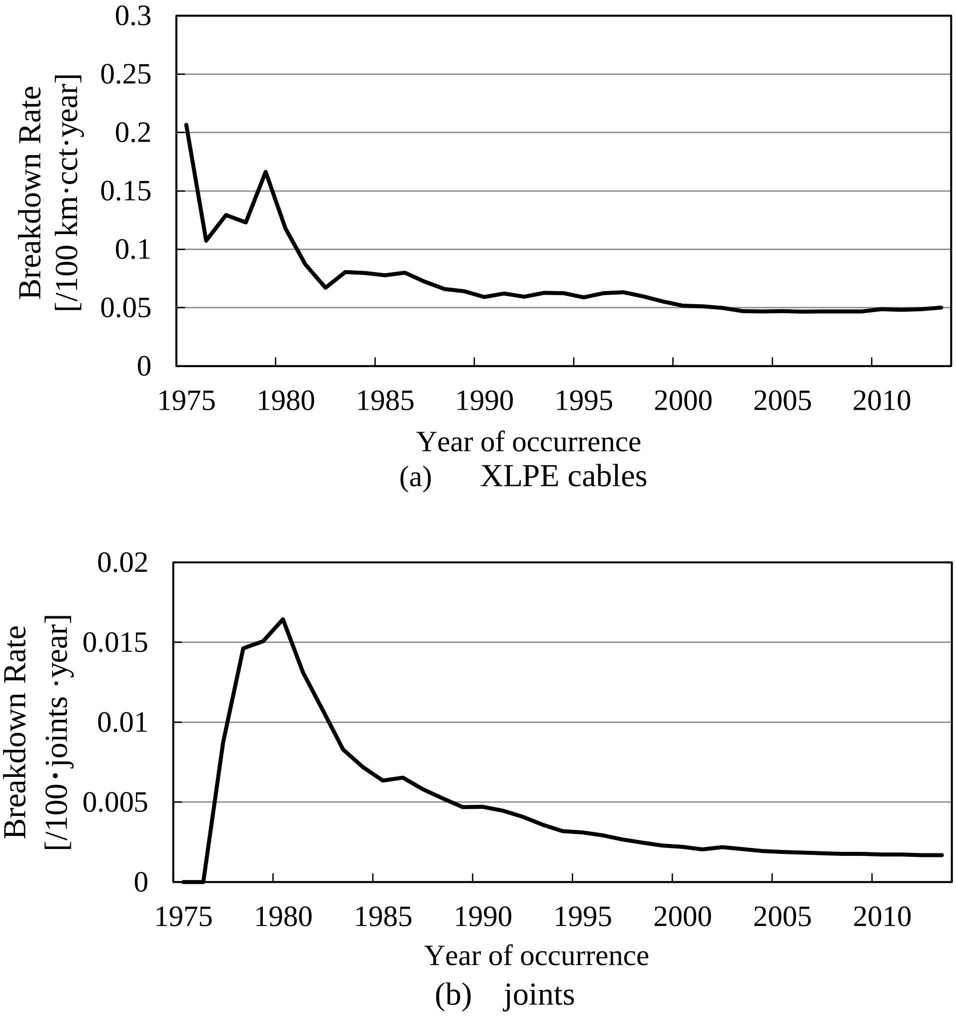
Underground Transmission Lines - Quality Management System - Dielectric Breakdown - Transmission System Operator

1. INTRODUCTION

In the electric power system, reducing breakdowns of facilities greatly contributes to a stable power supply. Breakdowns are caused by a wide variety of factors such as defective design, manufacturing, construction, and aging. Therefore, Japanese TSOs have been striving to improve the quality of their electric power systems by constructing systems based on a QMS. This paper focuses on the quality of underground transmission lines in Japan, and describes the situation of their dielectric breakdowns and the specific activities of a QMS used by Japanese TSOs.

2. BACKGROUND

The situation regarding facilities of underground transmission lines in Japan described below. The extra-high-voltage underground transmission lines owned by Japanese TSOs have a length of 18,110 km. Of these, cross-linked polyethylene (XLPE) cables account for 13,840 km. The dielectric breakdown occurrence rate of 66 kV-class lines for XLPE cables is reported to be about 0.05 [/100 km.cct.year] per year in the cable section. Figure (a) and (b) show the breakdown occurrence rates by year in the cable section and the joint section of 66 kV XLPE cables in Japan [1].



(a) XLPE cables

(b) joints

Figure 1 Breakdown rate of 66 kV XLPE cables

These show that the breakdown occurrence rate of 66 kV XLPE cables has been decreasing since 1980 even though high voltage test at commissioning test has been stopped for the transmission lines since 1998 after the introduction of new regulation by Japanese Goverment. On the other hand, the breakdown occurrence rate in the world is reported about 0.0939 [/100 km.year] as the breakdown rate in 60 – 109 kV XLPE cables according to the survey by CIGRE [2].

The main reason why the dielectric breakdown occurrence rate is lower and decreasing in Japan are considered to be resulted by the implementation of a QMS that is aimed for stably supplying electric power, securing public safety, conserving the environment, and having proper and efficient operation of business. Next, the activities of a QMS will be described. In addition, as other efforts to improve quality, Japanese TSOs have established information cooperation systems among TSOs and cable manufacturers. This effort will also be introduced.

3. EFFORTS TO IMPROVE QUALITY

3.1 Background to the Introduction of a QMS

This section describes the background to the introduction of a QMS in Japanese TSOs.
As the social environment surrounding the electric power industry changes drastically, such as alterations in the social structure, liberalization of electric power, and stagnation of demand, Japanese TSOs are increasingly required to respond appropriately to customer demands such as for the stable supply of electric power, public safety, and environmental preservation. In particular, although the working population will continue to decrease in the future, it is necessary to cope with the increasing aging of facilities. Therefore, Japanese TSOs have to promote business efficiency while maintaining and improving quality.
Under these circumstances, TSOs needed to establish their own QMS in addition to ISO 9001 or other national/international standard, in which they continuously maintain and improve business quality. The system referred to here is the framework shown below.
a)To have systematic development of operational manuals and clarification of rules and procedures
b)To implement for the Plan-Do-Check-Action (PDCA) cycle and continuous improvement in business operations
The details of specific efforts to operate a QMS are shown below.

3.2 Initiatives to Operate a QMS

3.2.1 Clarification of Rules

In order to develop an operation manual systematically, a number of rules are stipulated and classified into categories including matters to be observed, reference matters, and individual matters of offices. These documents such as those relating to design, construction, and maintenance are arranged by item.

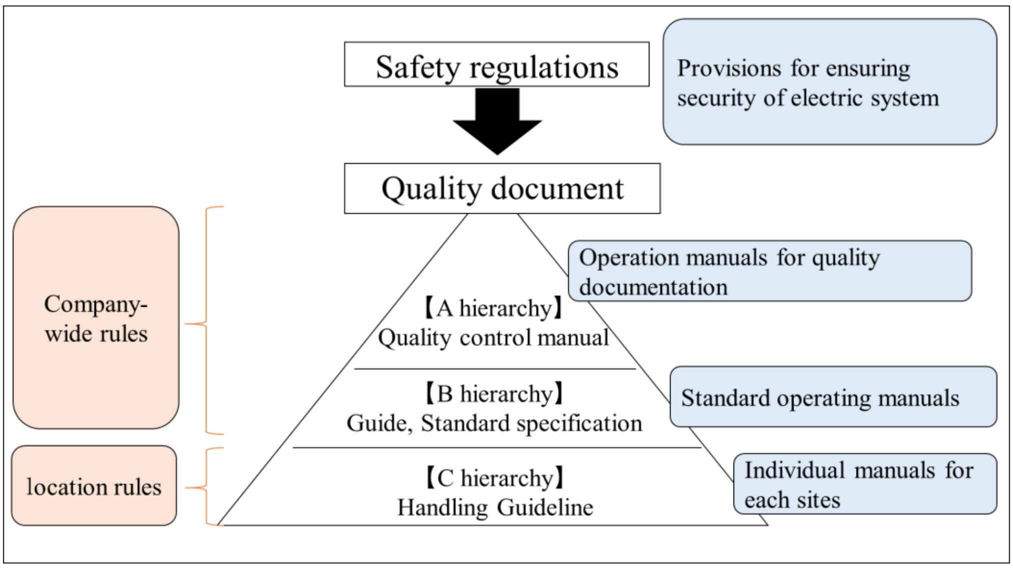


Figure 2 An example of a quality document system

The prepared operation manuals are called quality documents and can be viewed by anyone on the company's website. An example of a quality document system is shown in Figure 2.
By preparing such quality documents, it is possible not only to eliminate discrepancies in business quality due to local rules, but also clarify the roles of each employee and ensure accountability by securing evidence.
In addition, when quality documents are updated, employees are trained on the updated contents so that they can always work with the latest quality documents.

3.2.2 Improvement Activities Based on the PDCA Cycle

In continuous work improvement activities based on the PDCA cycle, TSOs set quality targets such as compliance with laws and regulations, prevention of occupational accidents, and improvement of the resilience facility. Based on this, each office will set detailed targets and carry out operations. Final confirmation of whether the planned targets have been achieved is done and improvement instructions are given by an independent audit department as a check.
These cycles are conducted based on the quality documents described above. However, if it is estimated that quality can be improved by reducing waste and introducing the latest technology, anyone can submit a proposal to the head office that manages the quality documents. One of the features in QMS is that these bottom-up types of improvement can be achieved. An example of a PDCA cycle in TSOs is shown in Figure 3.

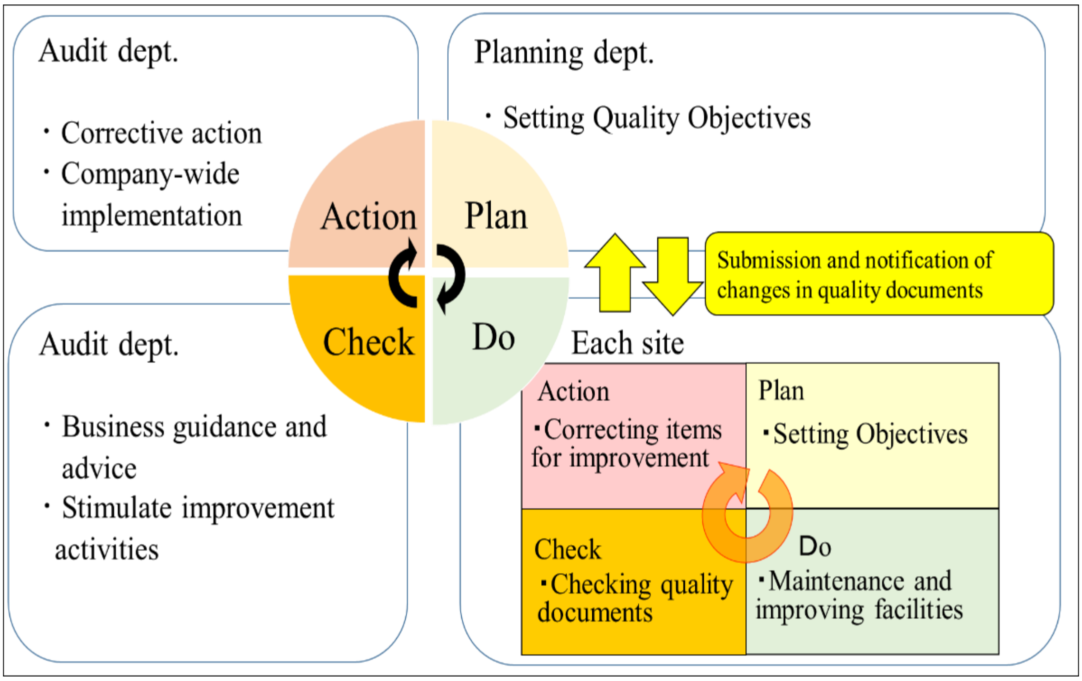


Figure 3 Example of PDCA cycle for domestic TSOs in QMS

In addition to the system for submitting and changing quality documents, some TSOs have established a proposal evaluation system in which employees are praised by their company based on their proposals that lead to enhancement of work efficiency and cost reduction.
In (1) and (2) above, an outline of the operation system was described. Next, the specific QMS activities for underground transmission lines are described in four stages: design, manufacturing, construction, and operation.
Representative quality targets at each stage of design, manufacturing, construction, and operation, and QMS activities to achieve those targets are shown in Table I.

Table I Typical quality targets and QMS activities

	Quality targets	QMS activities
Design	Improvement of design quality	・Clarification of design content ・Thorough examination
Manufacturing	Improvement of products quality	・Type approval system
Construction	Ensuring the construction quality	・Connection certification system ・Quality confirmation to construction company
Operation	Prevention of accidents Early restoration	・Preparation of measurement manual for equipment abnormality ・Spare materials for accident countermeasures

3.3 QMS Activities at Each Stage

3.3.1 Design

The quality goal in the construction design stage is to improve design quality. To do this, TSOs are mainly working on two points—clarification of design content, and thorough examination.

(1) Clarification of Design Content

When an employee designs underground transmission lines in Japan, it is necessary to carry out multiple designs according to the facility outline, such as pipeline design, manhole design, and cable layout design. In these designs, in order to ensure a certain level of quality or higher, the design is clarified by preparing a design manual for each design item. Table II shows the main items of the design manual.

Table II Example of design manuals

Items	**Description**
Basic design	Design basis of cable conductor size etc.
Duct design	Design basis of excavation methods, temporary construction etc.
Manhole design	Design basis of size, strength calculation of manhole flame etc.
Cable insulation design	Design basis of cable insulation thickness, stain resistant etc.
Cable laying design	Design basis of cable offset etc.
Bonding design	Design basis of bonding, cross bonding etc.
Over voltage resistant design	Design basis against over voltage such as lightning surge etc.

In these design manuals, design specifications, calculation formulas and numerical values for the calculation, concepts of design, and knowledge and background obtained from past trouble events are described, and designers can design with higher accuracy by confirming the information.
Since the design manual is a quality document described in section 3.2.1, bottom-up type improvements have been made. There are many cases in which the design contents are examined in each office and countermeasures based on a facility failure are reflected in quality documents.

(2) Thorough Examination

Some TSOs have introduced a check system to examine the design contents according to each stage, such as the basic design at the time of making a construction plan and the detailed design before ordering a construction. By repeatedly having the design contents examined by persons concerned other than the construction department, it is confirmed that there is no problem with conformity with technical standards and safety assurance, and a highly reliable design is realized.

3.3.2 Manufacturing

The quality goal at the manufacturing stage is to improve the quality of delivered products. TSOs are working to maintain and improve product quality by introducing a "type approval system." This is a system in which quality tests are conducted in advance for products that are installed in important equipment, are frequently used as common products, and are very difficult to manufacture. Only products that pass the quality tests can be purchased. Products covered by the type approval system are applicable not only to cables and joints but also to a wide range of items such as pipeline materials.
The TSOs periodically check the manufacturer's production lines and delivery materials to ensure that the quality of the approved product is maintained properly. An outline of the type approval system is shown in Figure 4.

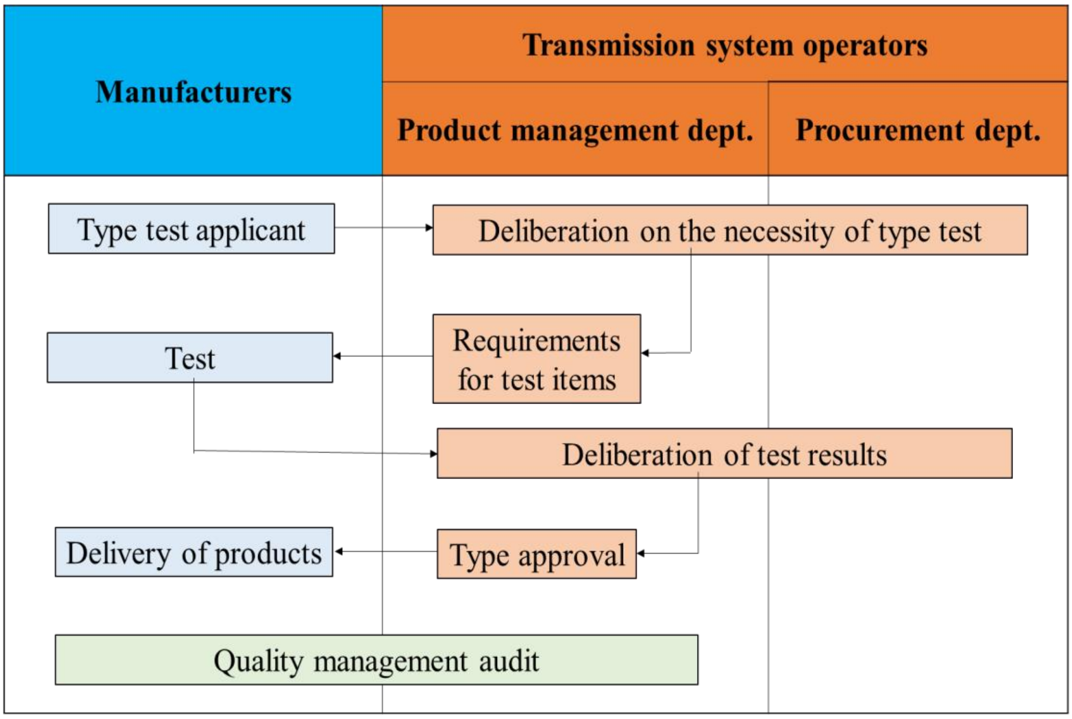


Figure 4 Flow of type approval system

By purchasing a product in the type approval system, TSOs can omit detailed design, and the manufacturers can omit inspection items. In addition, there are advantages such as reducing costs by unifying specifications, improving the efficiency of maintenance work, and enhancing facility reliability. In addition, since individual designs are required for a product that has not been approved in the system, some TSOs have established procedures in which a specialized engineering department, not a construction site, checks product specifications and decides whether to adopt it.

On the basis of placing orders and manufacturing these types of approved products, it is possible to deliver high-quality products and improve the operational efficiency in both manufacturers and TSOs.

3.3.3 Construction

The quality goal in the construction stage is to ensure construction quality. To do this, a certification system for cable joints has been established, and the quality control capability of construction companies has been confirmed. In Japan, not only cable manufacturers but also some local construction companies carry out cable connection work for voltage classes of 66 kV or less.

(1) Jointer Qualification System

The cable joiting work in a local construction company is carried out by authorized people based on a system to qualify cable jointers. For joint specifications, only workers who have mastered the characteristics and assembly procedure of the joints of each manufacturer can be engaged in the jointing work to ensure construction quality.
Qualification process includes training by manufacturer engineers, assembly tests of joints, and electrical tests of joints they assemble by themselves. In addition, regular jointing training is required for those who have obtained the qualification, and efforts are being made to maintain advanced cable jointing skills.

(2)Quality Confirmation to Construction Company

When placing an order for construction, the procurement department checks the quality control capability of the construction company, and selects an appropriate construction company based on the scale and difficulty of the construction. Before the start of construction, the construction company and the TSOs try to improve the quality by assessment of risks in the construction work and discussing riskmitigation measures. In addition, at each stage of construction, the TSOs have their own inspection records, so that they can inspect all construction companies with the same criteria, and efforts are being made to ensure construction quality. After the completion of construction, there are discussions on design and construction management between the TSOs and the construction company. This is linked to improving construction quality and customer satisfaction by incorporating opinions such as items that should be reflected in quality documents.

3.3.4 Operation

Quality targets at the operational stage are accident prevention and early recovery. The maintenance and management methods of the equipment and the measures to be taken in the event of equipment failure are specified in the manual, and various measures are taken for the purpose of early restoration in the event of failure.

(1) Preparation of Measurement Manual for Equipment Abnormality

In the inspection and repair work, any facility abnormality found in the inspection and the countermeasure method are made into a manual. In this manual, by clarifying the criteria to determine whether a repair is necessary or not, evaluation differences are prevented. This manual is also registered as a quality document, and newly discovered abnormalities and new repair methods are updated and shared internally.
From the viewpoint of accident prevention, some TSOs are trying to do this by newly introducing an online continuous monitoring system for joints. The development of information and communication technology (ICT) is expected to continue in the future, and efforts are being made to efficiently maintain and manage facilities using such technology.
Information and communication technology(ICT) is to use of computers and other electronic equipment and systems to collect, store, use, and send data electronically.

(2) Early Recovery

As for the early restoration in the event of a failure, a specific manual for dealing with the dielectric breakdown of underground transmission lines has been established in advance. The maintenance division regularly conducts failure response training to confirm the contents of the manual and discuss whether there are areas to be improved in order to boost recovery skills.
In addition, each TSOs possesses and manages spare materials for accident countermeasures for the purpose of early restoration. Also, some TSOs have own jointers as their employees for early restoration. By making efforts for early restoration in the case of such failure, customer satisfaction is improved and accountability to the local community is enhanced.

3.4 Quality Improvement through the Cooperation between TSOs

There are 10 TSOs in Japan, an island country that stretches from north to south. When a fault occurs, the cause is thoroughly investigated, and measures to prevent recurrence are shared among TSOs. These efforts have led to improvements in the quality of underground transmission lines in Japan. Figure 5 shows the flow from the occurrence of these failures to information-sharing at TSOs.

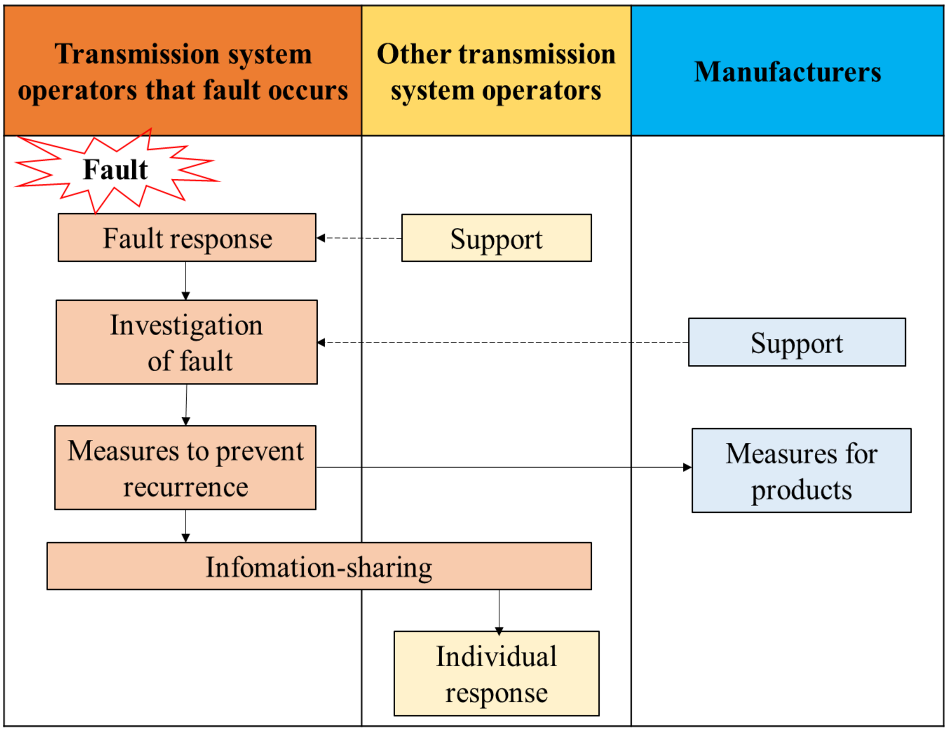


Figure 5 Flow from the occurrence of these failures to information-sharing

As an example of this, an incident in which a water tree (breakdown phenomenon resembling a tree branch in a cable insulation) is generated due to the intrusion of water into an XLPE cable insulation , resulting in a dielectric breakdown is described below. When an XLPE cable broke down, the TSOs cooperated with the manufacturer and clarified that the cause of the breakdown was moisture entering from outside of the cable. Based on these results, TSOs developed and adopted a cable with a water interception layer. By promptly sharing this information with TSOs, the number of failures caused by water trees decreased in Japan. In addition, since the knowledge that water intrusion leads to a dielectric breakdown was obtained, each TSOs took various measures for cable joints as well, such as reviewing the structure of the joints and the joint method to prevent recurrence.
TSO are also working to have cooperation among them in securing construction capabilities. In order to ensure a limited number of extra-high-voltage level jointers from manufacturers, the working days of

the jointer are adjusted in advance, according to the construction plan of each TSOs. As a result, a stable construction force can be secured, and a facility renewal plan can be planned and executed.
From the viewpoint of early restoration, information on spare materials for accident countermeasures possessed by each TSOs is shared among some TSOs, and a system for exchanging spare materials in an emergency is also under consideration.
In Japan, there is a research institute called the Central Research Institute of Electric Power Industry, which is jointly funded by TSOs in Japan. The institute conducts advanced research and development, and the research results are shared with TSOs in Japan, contributing to further quality improvement. The cooperation between TSOs described above is an effort made amid conditions where the companies ensure competition is not hindered and take thorough measures for information management.

4. CONCLUSION

In QMS activities, Japanese TSOs are cooperating to improve the quality of their power systems on a daily basis by clarifying rules and improving operations through the PDCA cycle. QMS is not an only document rules but more important acts in accordance with an established manual. QMS should activate employees' awareness of the need for enhancements, such as operational improvements and quality improvements. It also plays an important role in the improvement and succession of technological capabilities and lessons learned. These efforts have led to higher quality of underground transmission lines in Japan.
From the above, it can be said that the QMS largely contributes to the low failure rate of underground transmission lines in Japan.

BIBLIOGRAPHY

[1] Electric Technology Research Association,“Design and installation technology for XLPE cable system”, (Electric Technology Research Association Report Vol.73 No.2 (in Japanese) 2017, page 34).
[2] Working Group B1-57 CIGRE, “Update of service experience of HV underground and submarine cable systems” (September 2020, page 31).