Insulation monitoring of high voltage electrical equipment

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Kansai Electrical Safety Inspection Association

fisuel seminar – 15 and 16 October 2024

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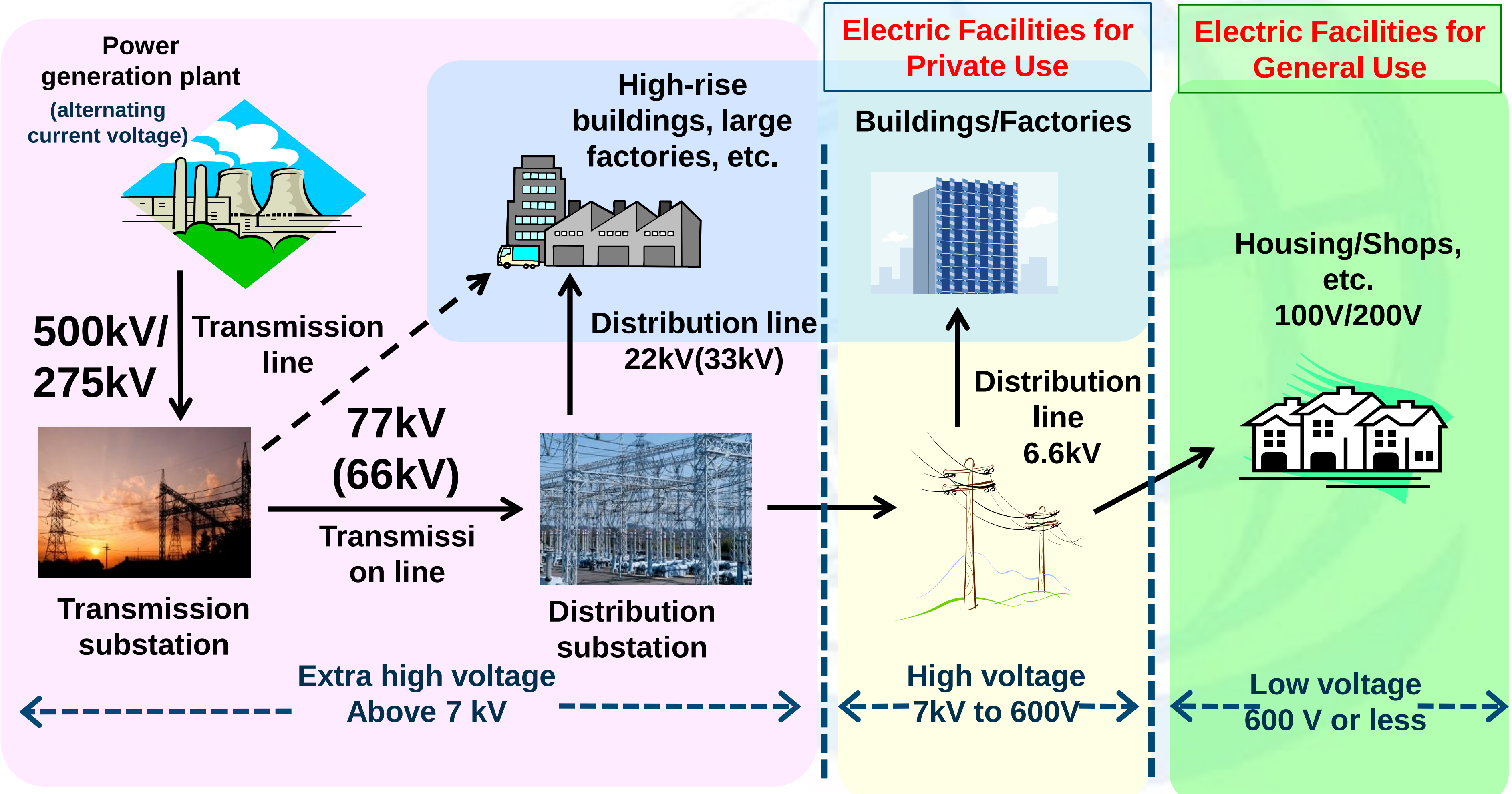
Introduction to the Kansai Electrical Safety Inspection Association

Management philosophy
"To provide maximum assurance by increasing the quality of safety with the best technologies and services."

Name: Kansai Electrical Safety Inspection Association (general foundation)
Location of the Head Office: 11th Floor, Nakanoshima Daibiru, 3-3-23, Nakanoshima, Kita-ku, Osaka-shi, Osaka-fu
Date of establishment: December 1, 1965
Number of employees: 1,551 (as of March 31, 2024)

Voltage classes and classification of electric facilities in Japan



Chief electrical engineer system for Electric Facilities for Private Use

Obligations of business operators

- To appoint a qualified engineer as the chief electrical engineer.
- To submit notification of the appointed chief electrical engineer to the national government.
- Personnel engaged in work in the place of electric utility business shall follow the instructions given by the chief electrical engineer.

Qualification and role of the chief electrical engineer

- A license is issued by the national government based on an application filed by a person who has a specified academic record and practical work experience or a person who has passed a national examination.
- The engineer shall fulfill the duties of safety, inspection, and supervision concerning the work, maintenance, and operation of electric facilities.

System of approval of outsourcing of a chief electrical engineer

- A place of business where high voltage electrical equipment is installed must appoint a chief electrical engineer pursuant to the laws and regulations. However, the place of business may avoid appoint of a chief electrical engineer, by concluding an outsourcing contract with a corporation or individual that meets certain requirements and by obtaining approval thereof from the administrative agency. The Kansai Electrical Safety Inspection Association performs safety, inspection, and management work of high voltage electrical equipment in place of customers, by utilizing this system of approval of outsourcing.

Contents of the business of the Kansai Electrical Safety Inspection Association

Investigation business (Electric Facilities for General Use)

<Outsourcing from an electric power company>

■ Regular investigation

In general households and shops, investigation of electrical equipment is carried out regularly to see if the equipment complies with the technical standards specified by the national government, and the results of such investigation are notified to the customers.

■ Construction completion investigation

In the same manner as in regular investigation, investigation is carried out when constructing a new building or at the time of extension or renovation, and the results of such investigation are notified to the customers.

Safety and inspection business (Electric Facilities for Private Use)

<Outsourcing from the business operator of a building or factory>

■ Chief electrical engineer outsourcing business

Safety, inspection, and management of high voltage power receiving equipment and part of the power generation equipment are performed.

■ Testing business

Inspection, measurement, and testing of the electrical equipment of a building or factory where there is a separate chief electrical engineer are performed. (Support business for such chief electrical engineer)

Public relations business

■ Public relations activities

Raising awareness, familiarization, and consultation on electricity use safety in close coordination with local communities.

■ Various types of lecture meetings

Holding various types of lecture meetings on electrical safety inspection, by visiting ordinary companies including those accepting outsourcing, neighborhood associations, schools, etc.

Work business

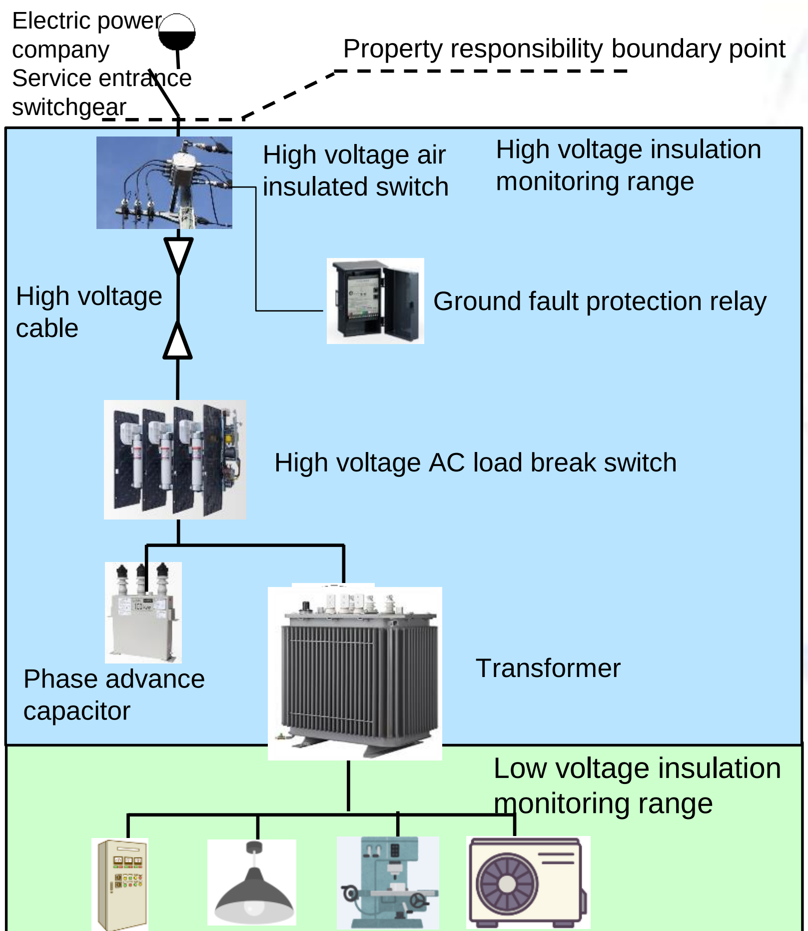
■ Electrical work

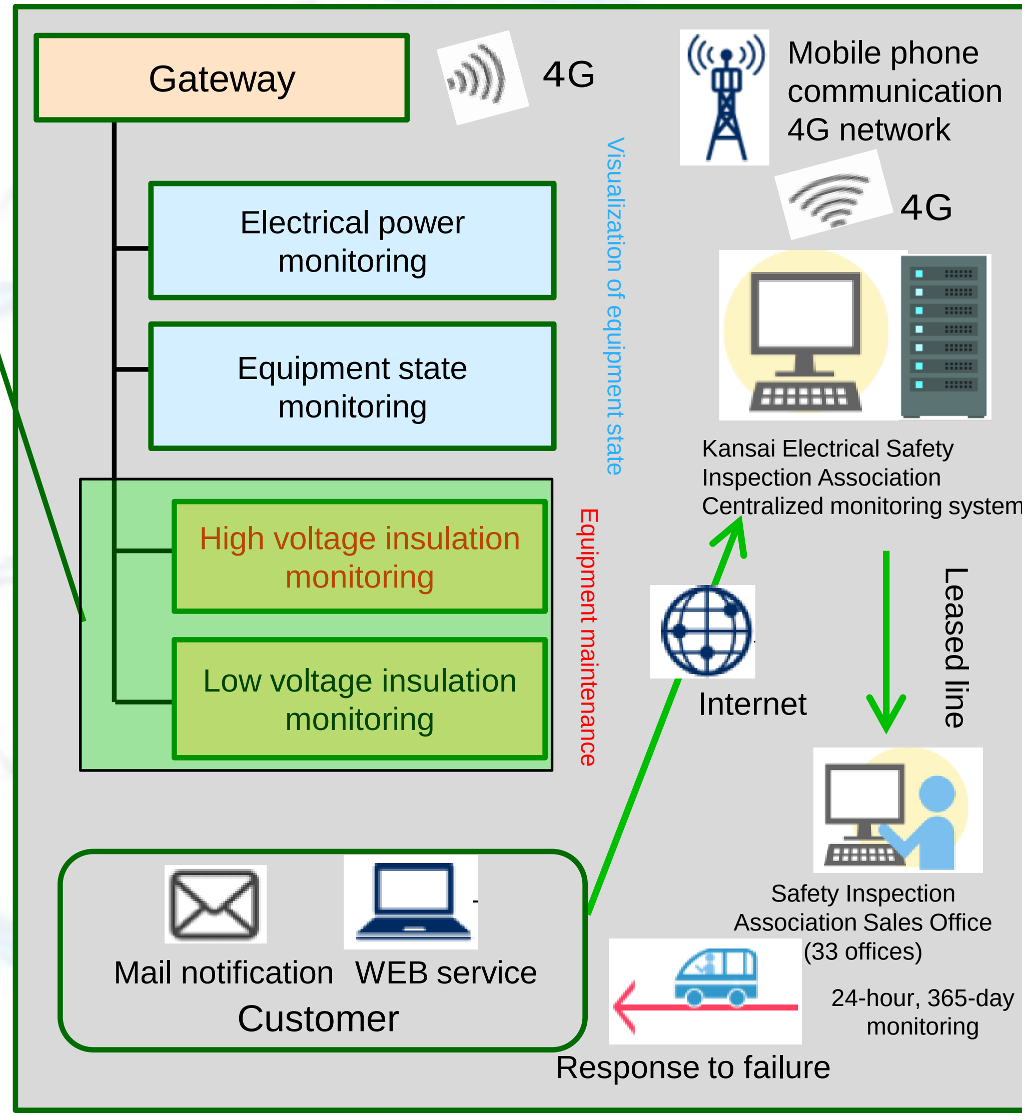
Performing electrical work such as equipment maintenance and energy saving measures, for customers concluding a contract with our Association.

Contents of safety inspection business (monitoring business)

Securing the safety of use of electricity by customers, assistance is provided for the prevention of power outage accidents and for the effective utilization of energy.

(Example) Real-time remote monitoring of circuits





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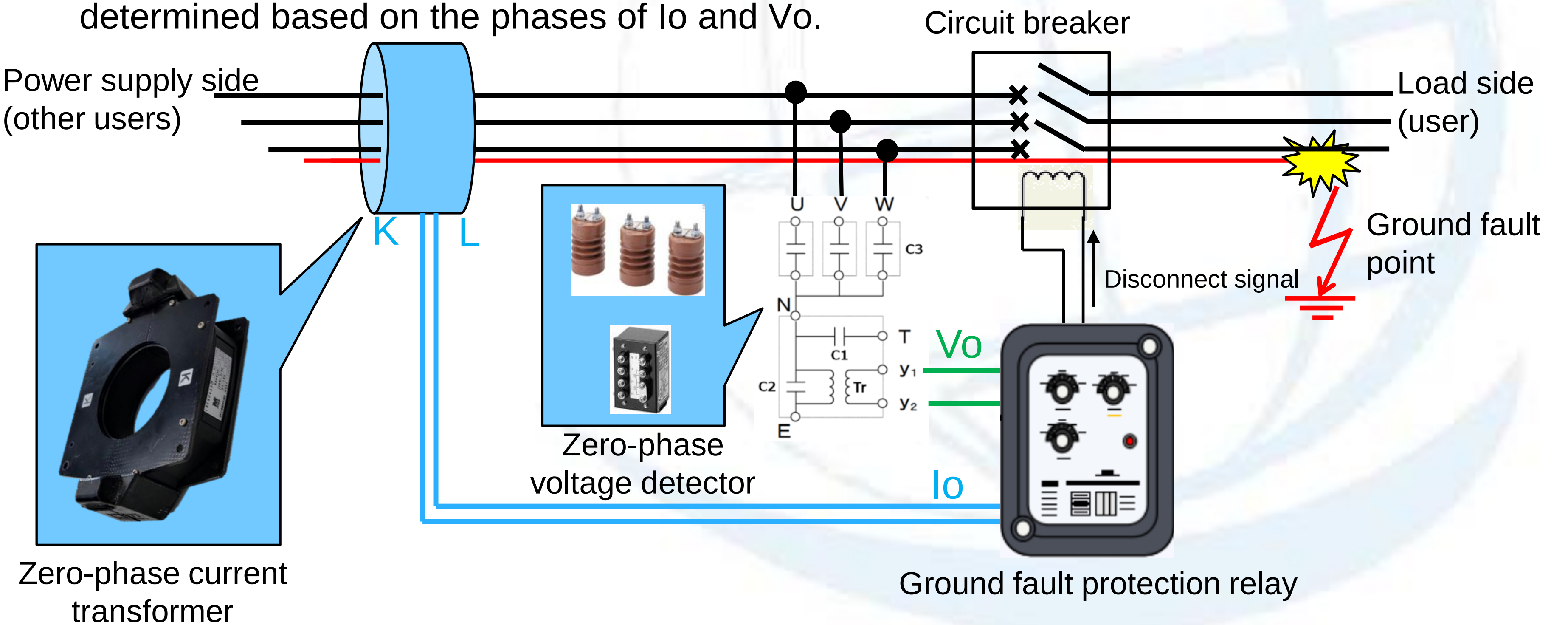
Results of dispatch to high voltage failures (accidents) of the Kansai Electrical Safety Inspection Association

- Among the 2,115 cases of electrical failures (accidents) involving high voltage circuit power outage that occurred in the customers of the Kansai Electrical Safety Inspection Association from 2021 to July 2024, 783 cases (37%) were caused by the activation of a ground fault protection relay.
- An electrical failure (accident) involving high voltage circuit power outage may affect a wide range in the premises of users, and at the same time may cause a ripple-effect accident*1.
- It can be expected that response by detecting insulation degradation in a high voltage circuit in an early stage will lead to the prevention of an abrupt power outage accident such as the one stated above.

*1. An accident that causes power outage involving the surrounding places of business other than the customer.

What is a ground fault protection relay?

- Abnormal zero-phase current (hereinafter called Io) and zero-phase voltage (hereinafter called Vo) that occur during a ground fault are detected, and a disconnect signal is transmitted to the circuit breaker.
- Whether the failure is a ground fault in the premises or a fault in any other user is determined based on the phases of Io and Vo.



About the methods of maintenance against ground fault accidents in a high voltage circuit

The methods of maintenance against ground fault accidents in a high voltage circuit can roughly be classified as follows.

	Insulation resistance value	Function	Contents
Preventive maintenance	100 GΩ to 100 MΩ	Diagnosis	Equipment diagnosis •Insulation resistance measurement •Direct current diagnosis
	200 kΩ or less	Monitoring	Monitoring system •Real-time monitoring of insulation resistance with live lines
Breakdown maintenance	20 kΩ or less	Protection	Protection system •Separation of accident points by using a ground fault protection relay and a circuit breaker (switchgear) (prevention of expansion of a ground fault)

- In maintenance by using a monitoring system, the deterioration state of a high voltage circuit is detected in a stage before the protection system is activated. Therefore, it is possible to prevent a loss caused by sudden power outage.

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Introduction to a high voltage insulation monitoring system

What is a high voltage insulation monitoring system?

- The system always measures very small currents and voltages that present the signs of insulation deterioration, and when any abnormality has occurred, it gives notice by means of an alarm.
- It analyzes abnormal phenomena that become the signs of an accident, and estimates the areas of failure.
- It contributes to the prevention of accidents and to early response in the event of an accident, by always monitoring the insulation.

History of high voltage insulation monitoring at the Kansai Electrical Safety Inspection Association

1987	Started the development of a high voltage insulation monitoring system.
1995	Put the high voltage insulation monitoring services into operation.
1997	The Shibusawa Prize was awarded to the Association.
1999	Received a patent (Japanese Patent Laid-Open No. 11-271384)
2005	Started multi-functional monitoring such as low voltage insulation, instantaneous interruption , analog monitoring, etc., in addition to high voltage insulation monitoring.
2010	Posted in the Standard Construction Specifications of MLIT.
2021	Started waveform analysis by means of the AI waveform analysis technique.
April 2022	Released high voltage monitoring for multiple circuits.
July 2023	Released high voltage monitoring for single circuits.

In the Kansai region, about 2,000 customers have adopted the high voltage insulation monitoring services.

High voltage insulation monitoring system

Initial type high voltage insulation monitoring system (1995–)

Equipped with the New Technology

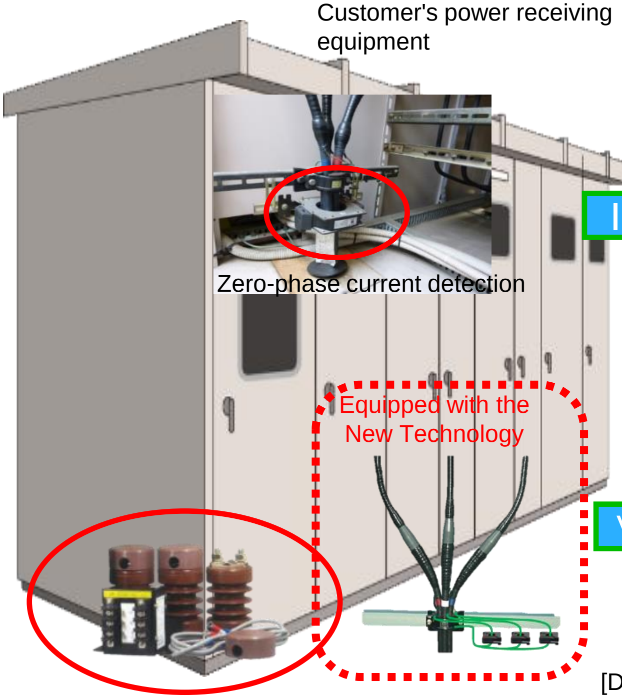
High voltage insulation monitoring system for multiple circuits (2022–)

High voltage insulation monitoring system for single circuits (2023–)

Overview of high voltage insulation monitoring services

Internet

High voltage (6.6 kV)
Customer's power receiving equipment



Zero-phase voltage detection

Io

Vo

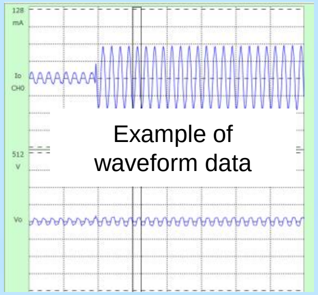
- Transmits an alarm when detecting abnormality
- Transmits waveform data

4G communication

Equipped with the New Technology

High voltage insulation monitoring system

Centralized monitoring command center



From the alarm waveform data sent to the server, the system estimates the causes comprehensively by combining the automatic waveform analysis (AI analysis), visual analyses, and interviewing the customer.

[Dispatch of personnel]
Searching failure areas
Cause investigation and response

<Examples of installation>

Facilities subjected to great damage caused by power outage, such as factories with production lines, calculation centers, complex buildings, public facilities, and general hospitals

Principle of detection of the high voltage insulation state of the Kansai Electrical Safety Inspection Association (New Technology)

The principle of the high voltage insulation monitoring system is roughly classified into three features: (1) Ground fault resistance monitoring (Rg monitoring), (2) Io pulse monitoring, and (3) Fault circuit distinction.

(1) Ground fault resistance monitoring (Rg monitoring)

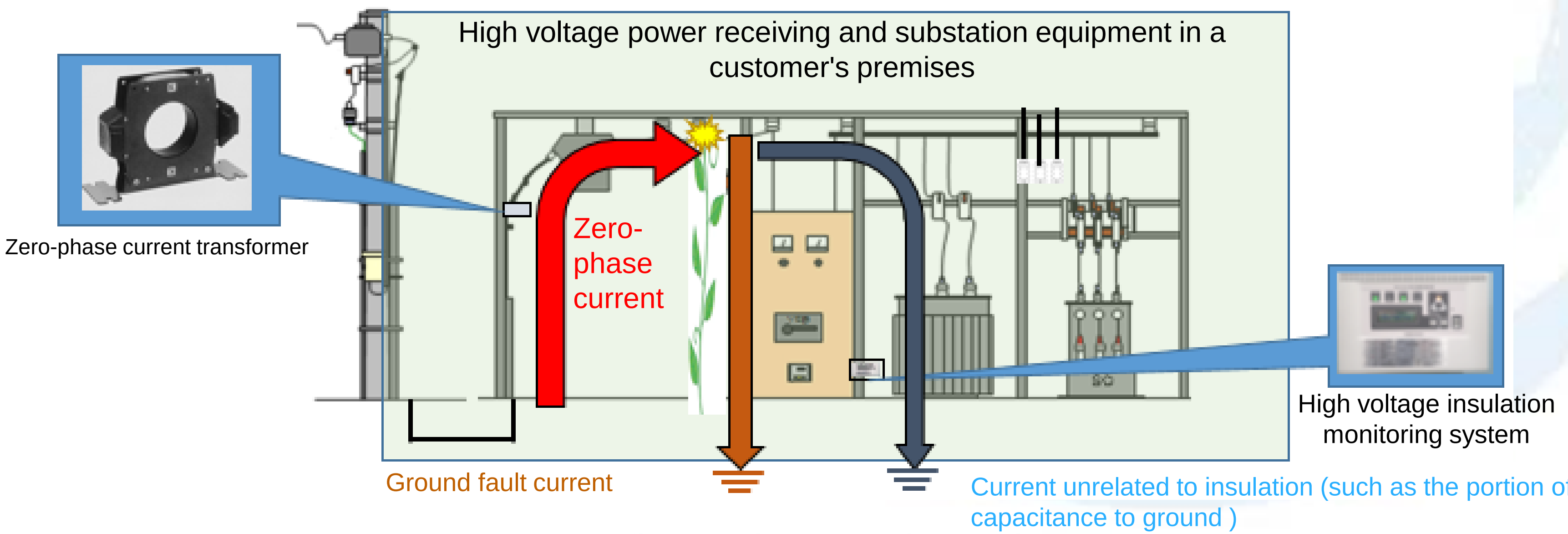
- In a common ground fault relay, monitoring is performed by using Io that is detected in a zero-phase current transformer, whereas our Association has enabled detection of ground fault currents with higher accuracy, by means of vector calculations (subtracting currents unrelated to insulation).

(2) Io pulse monitoring

- Ground fault with high fault resistance detection function when intermittent arcing has occurred in a high voltage cable

(3) Fault circuit distinction

Ground fault resistance monitoring (Rg monitoring) of a high voltage insulation monitoring system



(1) Principle of the ground fault resistance monitoring (Rg monitoring)

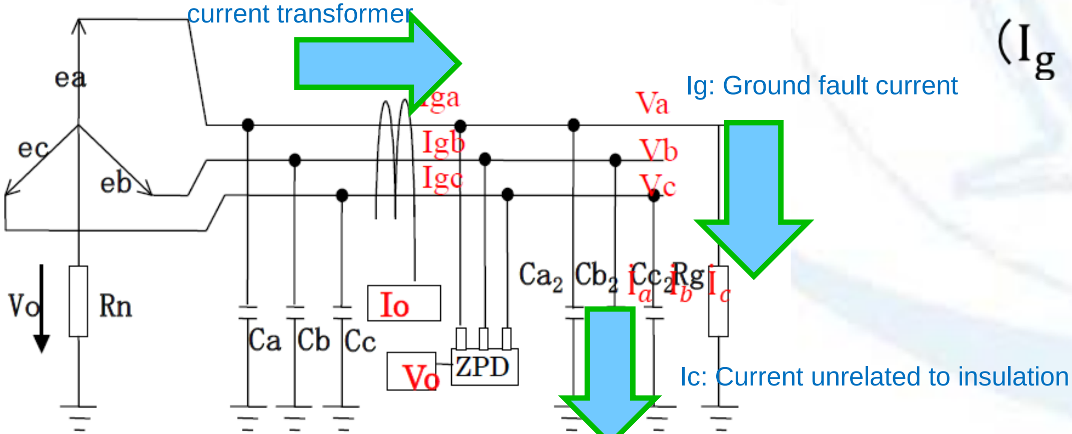
When it has been detected that the value of ground fault resistance Rg is equal to or less than the set value for monitoring, an alarm goes off.

Item	Details
Overview	Zero-phase voltage Vo and zero-phase current Io are measured, and the premises constant is calculated from the portion of change in these values.
Condition of occurrence	When ground fault resistance Rg in calculation is reduced to a value less than the monitoring level (200 kΩ)

The value of ground fault resistance Rg is obtained by the following calculation.

$$R_g = \frac{V_{Rg}}{I_g} = \frac{\sqrt{e_a^2 - V_o^2}}{I_g} = \frac{\sqrt{3810^2 - V_o^2}}{I_g}$$

Io: Zero-phase current detected by the zero-phase current transformer



6.6 kV ungrounded neutral system
(High voltage service entrance power receiving system in Japan)

Current unrelated to insulation that flows through the premises admittance to ground Y = ωC due to Vo in the distribution line

$$(I_g = I_o + \underline{Y \cdot V_o} - \underline{I_f})$$

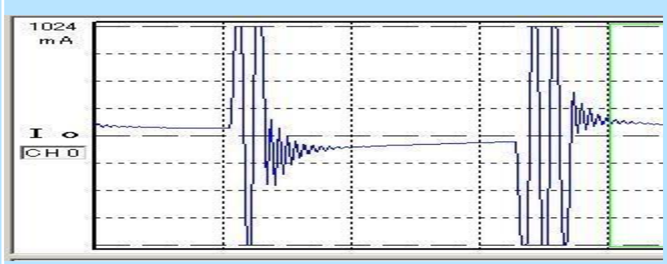
Current unrelated to insulation that is generated by imbalance of the premises capacitances to ground (Ca2,Cb2,Cc2)

(2) Principle of Io pulse monitoring

Item	Details
Overview	The large current pulses of Io are detected.
Condition of occurrence	They are generated when both of the following two conditions are met (AND condition). 1.When detecting the number of pulses greater than the pulse count value that has been set at either of the positive and negative (+, -) polarities, during one cycle of commercial frequency 2.During Io measurement overflow (An instantaneous peak value is about 10 Ap or more)

Item	Set value (initial value)
Number of pulses counted	0 to 255 （3）

During insulation degradation of the high voltage cable, the following characteristic Io waveform appears.

Features of waveform	Waveform	Features
Pulsed		Steep waveform involving needle-like or free vibration that occurs during an extremely short period of time A lightning surge and a switching surge have such waveform, including the waveform in a high voltage cable, etc. (The lightning surge and switching surge are distinguished from the periodicity of waveform or from the features of the preceding and succeeding waveforms.)

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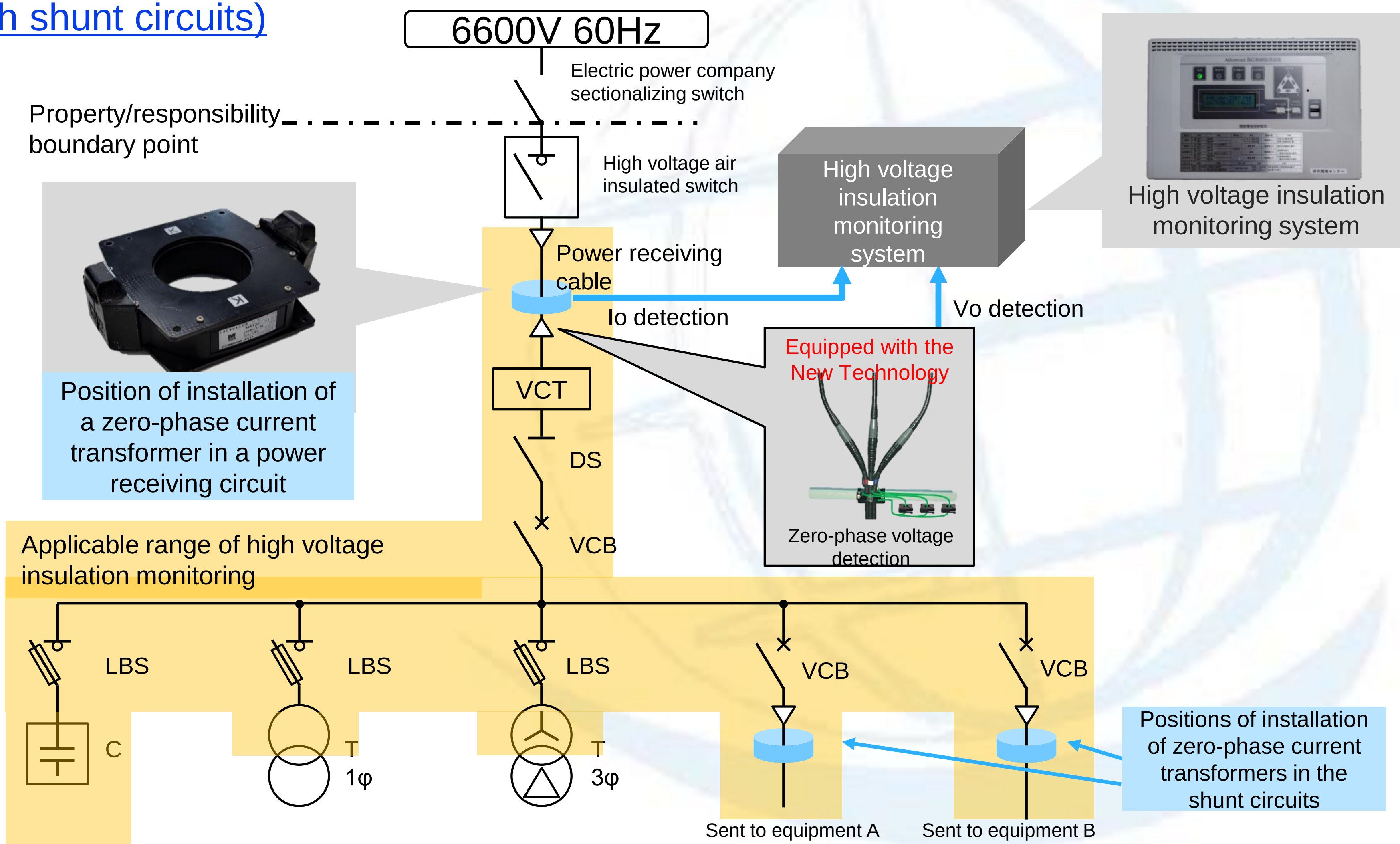
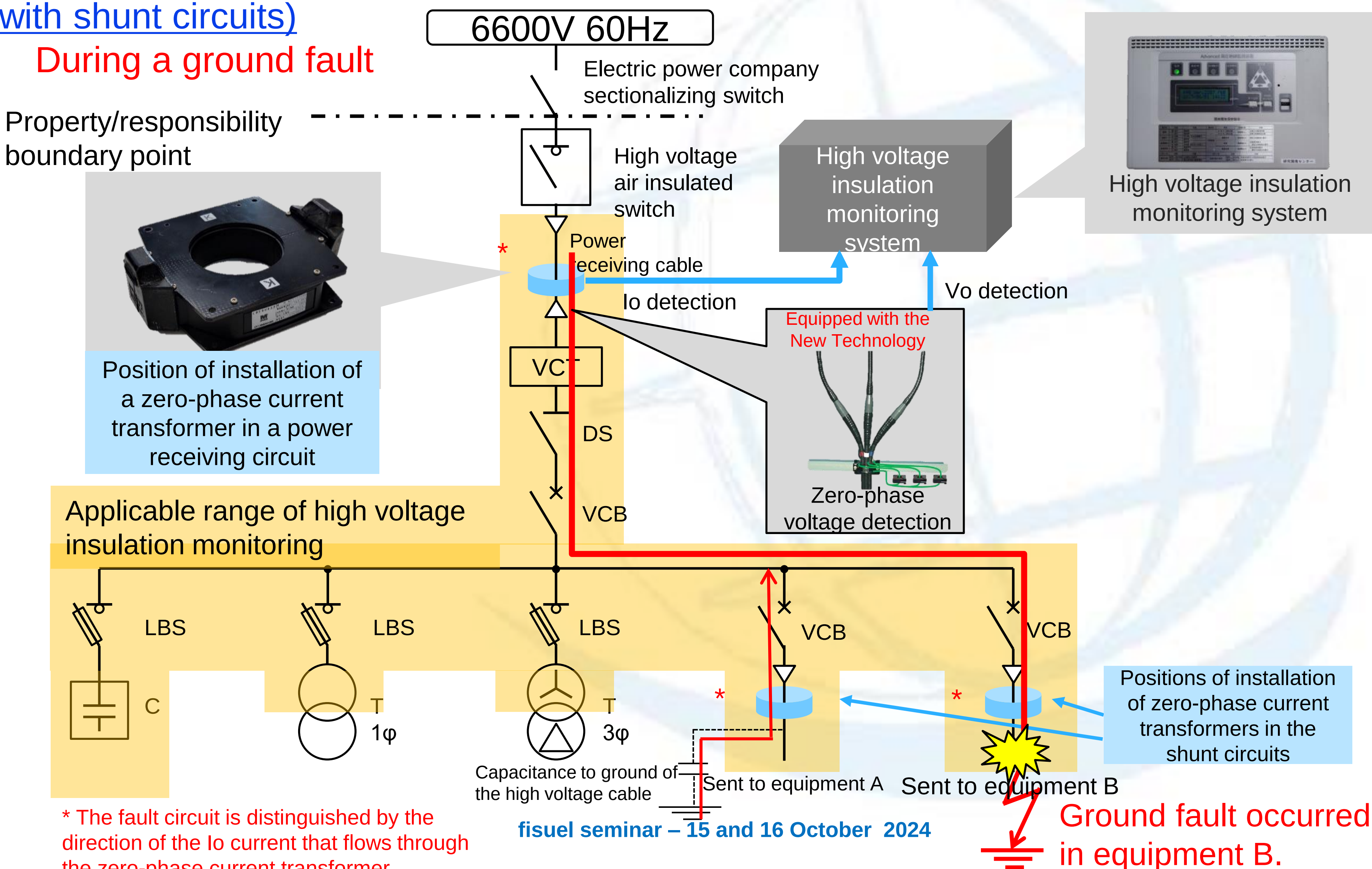
International Federation for the Safety of Electricity Users
Federacion Internacional para la Seguridad de los Usuarios de la Electricidad

Example of installation of a high pressure insulation monitoring system (with shunt circuits)



Example of installation of a high pressure insulation monitoring system (with shunt circuits)

During a ground fault



* The fault circuit is distinguished by the direction of the Io current that flows through the zero-phase current transformer.

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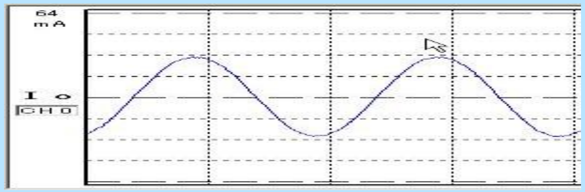
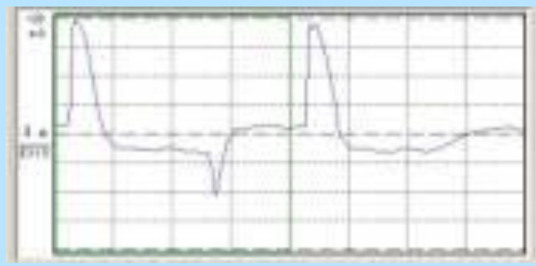
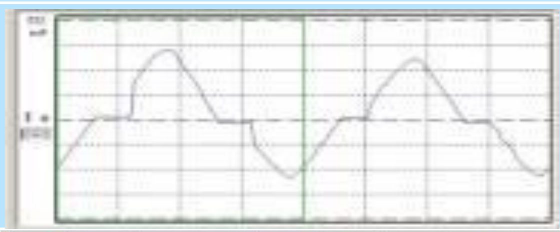
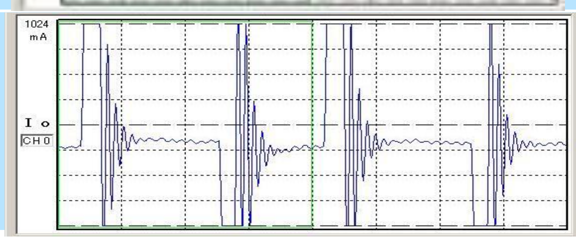
Features of Io alarm waveform

Features of waveform	Waveform	Features
Sinusoidal waveform		Waveform of a sine curve It mainly includes the waveforms of insulation degradation mainly due to wind and rain or dirt on the insulator, etc.
Creeping discharge		Waveform in which, when comparing the positive and negative waveforms, only either of the waveforms is extremely larger, as though having been subjected to half-wave rectification. In the case of this example, the positive is larger and the negative is smaller. It includes very small currents that flow on the surface of an insulator, etc.
Air discharge		Waveform in which a delayed discharge is seen at point zero. It includes contact with other objects or the like and gap discharge of insulators.
Pulsed		Waveform involving needle-like or free vibration Steep waveform that occurs during an extremely short period of time. A lightning surge and a switching surge have such waveform, including the waveform in a high voltage cable, etc.

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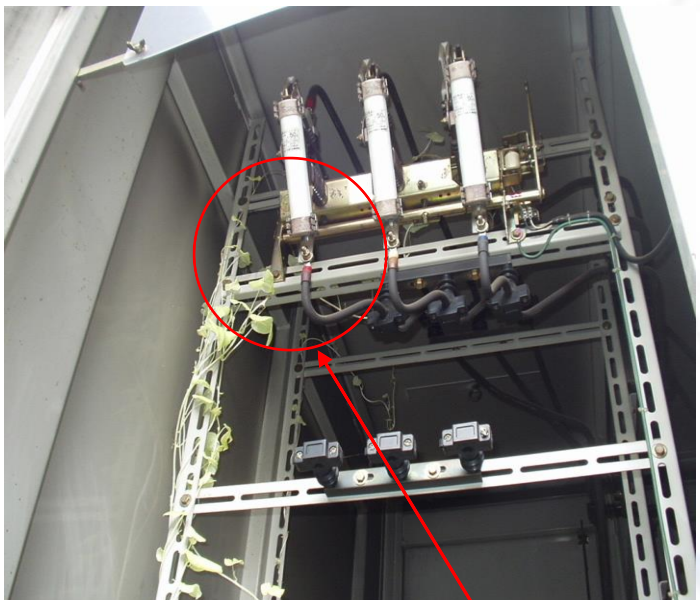
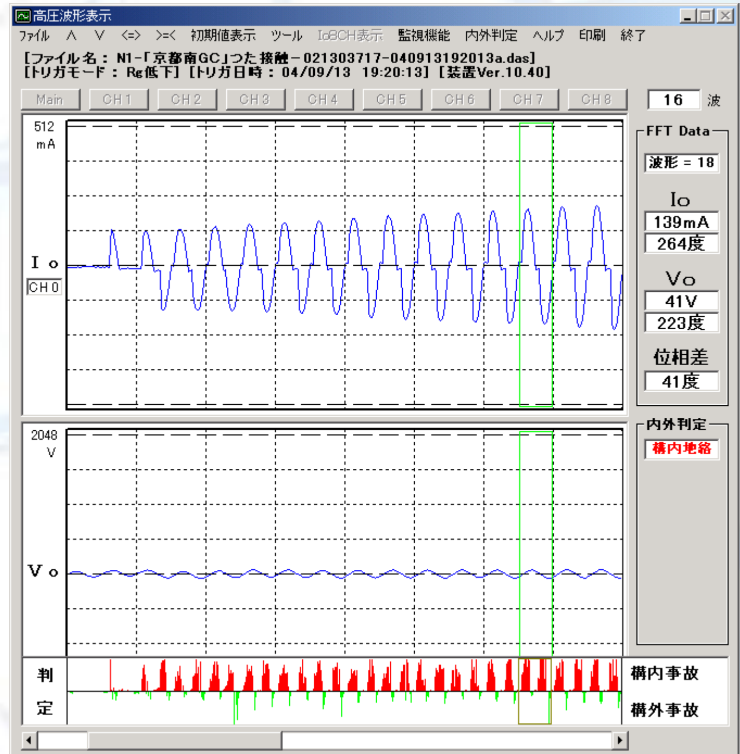
Example of characteristic alarm waveform (contact with other objects)

(Contact of a vine with the energized part)
A vine entered the inside of power receiving equipment and contacted its energized part. No power outage occurred due to the very small ground fault.



Io

Vo

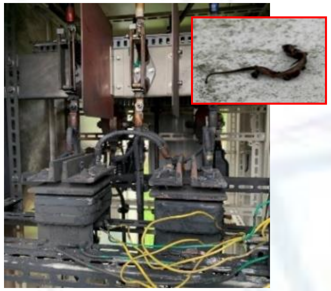
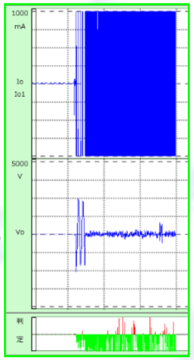


Alarm waveform

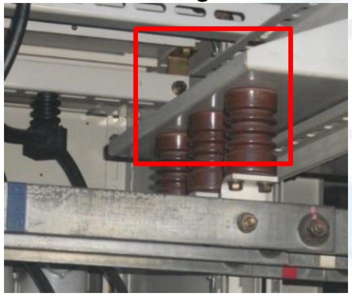
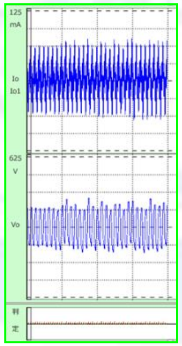
Area of the ground fault

Examples of signs of electrical equipment failure captured by a high voltage insulation monitoring system and alarms

<Example of simultaneous detection of abnormality with a power outage accident>

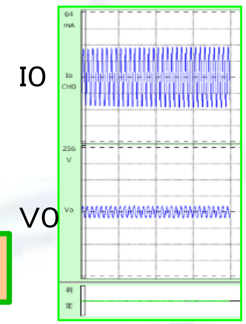
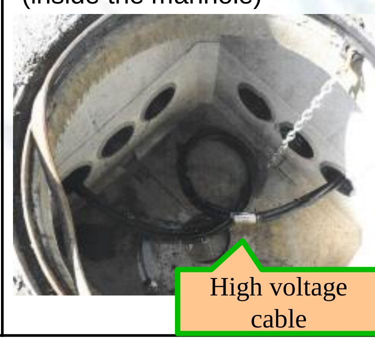
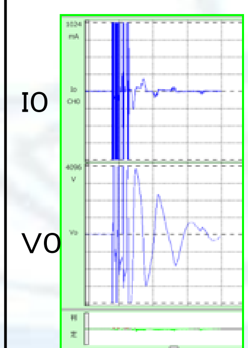
	Customer	Response to abnormal phenomena	Status photo	Alarm waveform	Remarks
1	Resin factory Power receiving capacity: 1,700 kVA (Date and time of alarm occurrence: September 13, 2021 at 22:43) Automatic cause analysis: "Small animal: gecko, etc."	An accident of burn due to a ground fault and a short circuit caused by contact of a gecko with the potential transformer inside the outdoor cubicle Response: Tentative recovery on September 15, 2021; full-fledged recovery implemented in the following month	**Severely burnt equipment and the gecko that contacted the energized part (in the red frame)** 	IO VO 	Early recovery is possible even when a power outage accident occurs, because the cause can be identified in a short period of time by the high voltage insulation monitoring system.

<Example of the prevention of a power outage accident by capturing its signs before the occurrence of such accident>

	Customer	Response to abnormal phenomena	Status photo	Alarm waveform	Remarks
2	Industrial waste treatment plant Power receiving capacity: 3,437 kVA (Date and time of alarm occurrence: June 12, 2020 at 07:42) Automatic cause analysis: "Insulation degradation: Dirt on equipment Insulators"	Insulation degradation caused by dirt on the epoxy resin inside the outdoor cubicle Response: Replacement of about 100 pieces of the applicable insulators on June 30, 2020	**Insulators of which insulation degradation** 	IO VO 	**<u>If the insulators were left as they were</u>** Power outage would occur in the entire plant and recovery could require several hours. There was an example of a similar phenomenon in which the signs were captured by the occurrence of an alarm and the epoxy resin insulators having poor insulation were removed. (April 23, 2024)

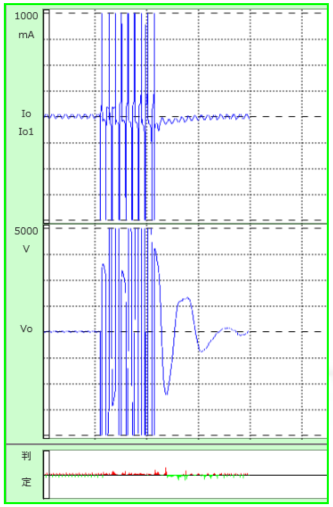
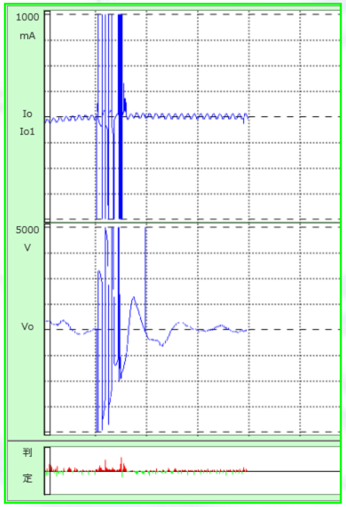
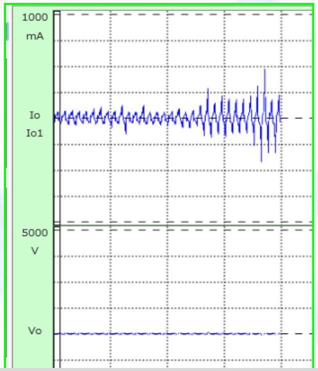
Examples of signs of electrical equipment failure captured by a high voltage insulation monitoring system and alarms

<Example of the prevention of a power outage accident by capturing its signs before the occurrence of such accident>

	Customer	Response to abnormal phenomena	Status photo	Alarm waveform	Remarks
3	Complex commercial facility Power receiving capacity: 3,300 kVA (Date and time of alarm occurrence: November 16, 2021 at 11:32) Automatic cause analysis: "Insulation degradation: Dirt on equipment"	Insulation deterioration caused by dirt on the high voltage vacuum circuit breaker inside the rooftop cubicle Response: Replacement of the circuit breaker	Inside of the dirty equipment 		**<u>If the circuit breaker was left as it was</u>** Power outage would occur in the entire building and recovery could require several hours.
4	Child care facility Power receiving capacity: 1,100 kVA (Date and time of alarm occurrence: April 28, 2023 at 06:46) Automatic cause analysis: "Insulation degradation: Cable"	Insulation degradation of a high voltage cable (line length : 230 m, 38 mm^2) Response: Replacement of the cable on June 9, 2023 (The insulation degradation (insulation resistance value: less than 1 GΩ) was found during the replacement.)	**High voltage cable of which insulation degradation occurred** (inside the manhole) 		**<u>If the cable was left as it was</u>** Power outage would occur in the entire building and recovery could require several hours.

Detection of the signs of high voltage cable dielectric breakdown

- Date and time of occurrence: August 26, 2021 (Thu.) Weather: fine
- Place of occurrence: Certain private combined middle and high school
- Overview:
  - The said customer was found to have insulation degradation of a high voltage cable for power receiving in the annual inspection carried out on August 14, and activation of the abnormal alarm of the high voltage insulation monitoring started on August 17. This case was the first activation of the high voltage abnormality alarm at this customer, and replacement work was scheduled to be performed on September 5 (Sunday).
  - On August 26, i.e. 9 days before the date scheduled for the replacement work, dielectric breakdown occurred in the said cable, and power outage occurred in the entire premises. However, since preparation for the cable replacement work had been made, after the accident, recovery work was completed in several hours.

	(1) 9 days before August 17 (Tue.) 16:55:32	(2) 23 hours before August 25 (Wed.) 13:04:11	(3) Immediately before power outage August 26 (Thu.) 12:01:17
Alarm waveform			 Immediately before power outage, similar abnormal waveform occurred 3 times consecutively.
Automatic cause analysis	(In the premises) Cable 1st, Equipment breakdown 2nd	(In the premises) Cable 1st, Equipment breakdown 2nd	(In the premises) Equipment breakdown 1st, Small animal 2nd

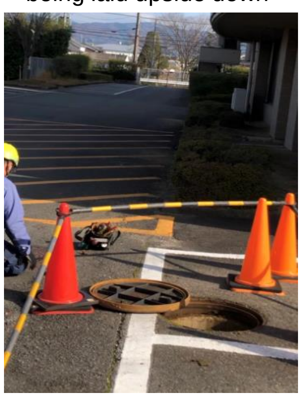
Partly because the signs had been captured at a relatively early stage of 9 days before, the situation led to early recovery after the accident.

Example of non-activation of a ground fault relay in a high voltage cable dielectric breakdown accident

1. Overview of the accident

- Date of occurrence: December 11, 2020 (Fri.)
- Place of occurrence: (Public facility)
- Situation: Dielectric breakdown occurred in the high voltage cable in a manhole, which ignited combustible gases, and the lid of the manhole opened and was laid upside down. However, the ground fault relay was not activated, and no power outage occurred in the distribution line as well. (As a result of measurement of the high voltage cable insulation resistance (G measurement), the value was 0.01 GΩ at 6 kV in the 3 wires together: cable defect.)
  Recovery was made by replacing the said sable on December 13 (Sun.).
- High voltage underground cable: manufactured in 2010, line length: 145 m, size: 60 mm^3
- Others: The cause of the occurrence of combustible gases was unknown (gas measurement was made at a later date, but no gases were detected).
  The dielectric breakdown of the cable was caused by water treeing .

State of the lid of the manhole being laid upside down



State of the inside of the manhole

Manufacturer's report

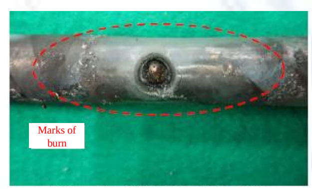


Photo-15 Surface of the insulator (around the breakdown hole)

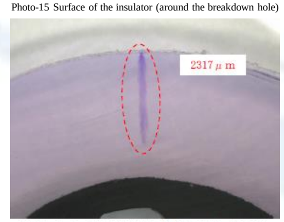
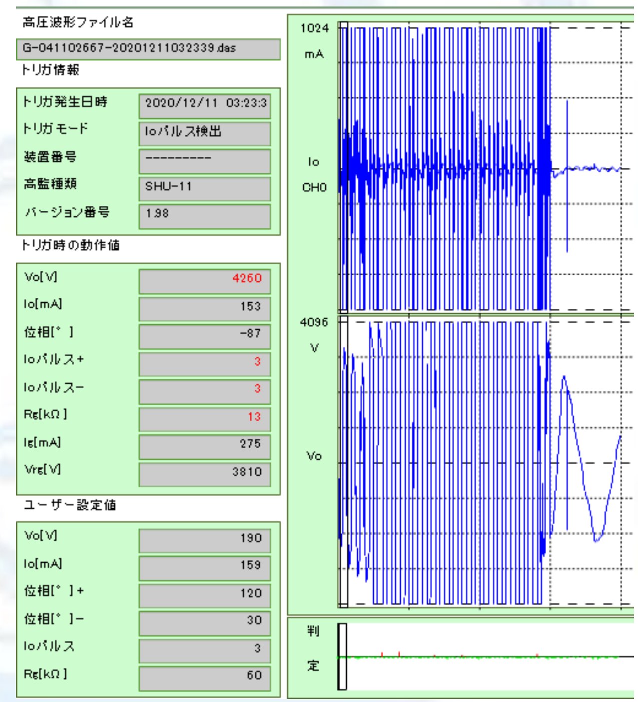


Photo-37 Red phase of the same blue phase breakdown hole (50 times)

Alarm waveform detected by the high voltage insulation monitoring system on the same distribution line

Ground fault accident continuation time: 0.4 seconds (24 cycles (1 square = 8 cycles x 3))



*: Usually, when the continuation time of a ground fault accidents reaches 0.5 seconds or more, the ground fault protection relay on the distribution line (on the side of the electric power company's substation) is activated, and power outage of the distribution line occurs.
In the above case, we presume that no power outage of the distribution line occurred because the continuation time of the ground fault current was about 0.4 seconds (24 cycles). (See the figure on the right.)

Example of non-activation of a ground fault relay in a high voltage cable dielectric breakdown accident

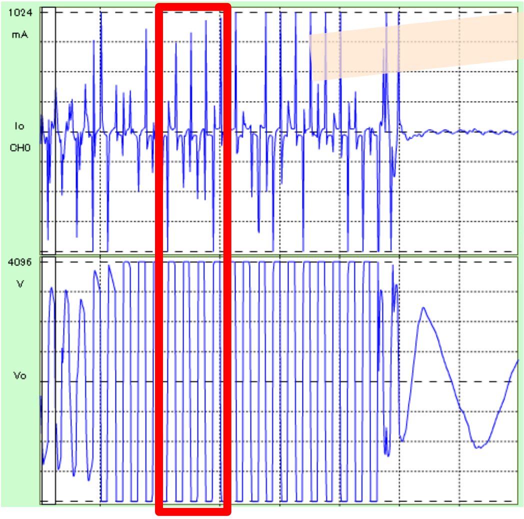
2. Reason for the non-activation of the ground fault protection relay

The pulsed intermittent arcing ground fault that is peculiar to a high voltage cable accident has a time band in which the ground fault disappears as shown in the figure on the right, and it is considered that the time required for activation of the ground fault relay was not reached.

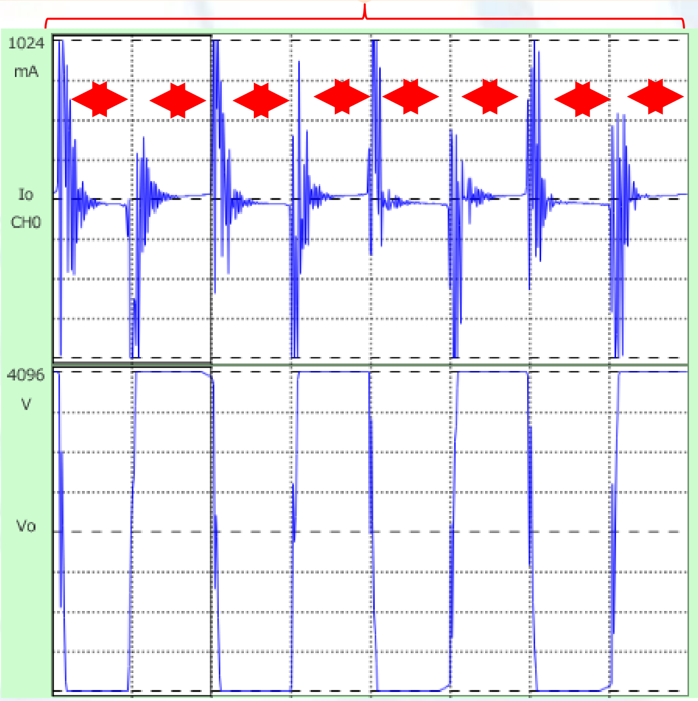
In the example shown in the figure below, during the continuation time of the ground fault, **there is the time band in which the ground fault disappears (↔), and the time band is not counted into the activation time of the ground fault protection relay.**

[Opinion of the manufacturer of the ground fault protection relay]
During detection of a ground fault current, if the time band in which the ground fault disappears is less than 0.04 seconds, the count is stopped, and so the relay would act as though the activation time has been prolonged.

Waveform of the intermittent arcing ground fault current



Enlargement of the X-axis



MERCI – THANKS

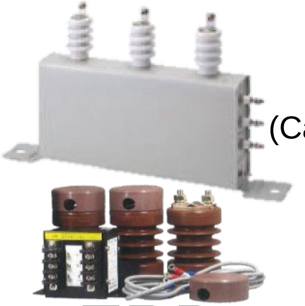
If you have information on good practices with new technologies utilizing AI/IoT, kindly share such information with us forwarding the following email address.

Kansai Electrical Safety Inspection Association
E-mail: setsuden@ksdh.or.jp

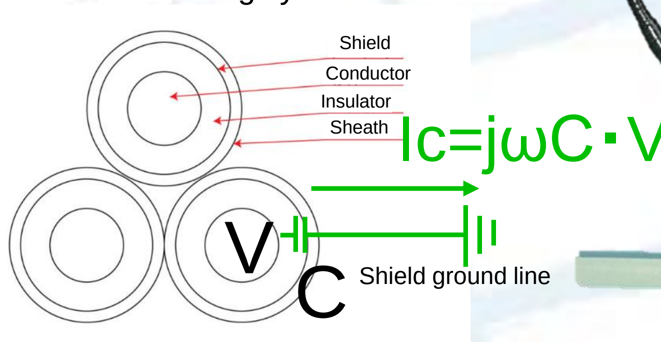
Appendix

Improvement of the zero-phase voltage (Vo) detection method of insulation monitoring systems

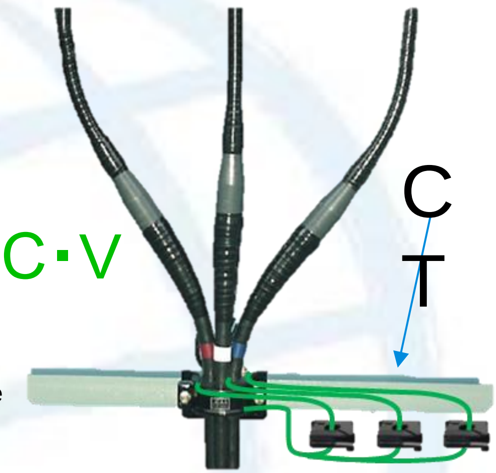
[Conventional method]
Detection of Vo by means of a ZPD connected to the high voltage bus



[3CT method]
Adopted in the latest high voltage insulation monitoring system



Actual state of work



A current proportional to the voltage to ground V is generated in the shield ground line of the high voltage cable. From this current, the voltage of each phase can be measured (at the same time, Vo can be calculated).

Advantages of the 3CT method
(1) Cost reduction corresponding to the portion of ZPD
(2) Improved reliability (decrease in the number of pieces of high voltage connection equipment)
(3) Reduction of the installation work time (power outage time)

Challenges of the 3CT method
(1) Very small shield ground line current => Contrivances in circuit design, anti-noise measures, compensation in line with CT characteristics, etc.
(2) Accurate capacitance measurement => Since calculation from the catalog value and the cable length involves a large error, dedicated measuring equipment shall be developed separately.

Capacitance measuring equipment

Capacitance is calculated from the current flowing through the shield ground wire of the high voltage cable.

Principle of calculation of Vo (3CT)

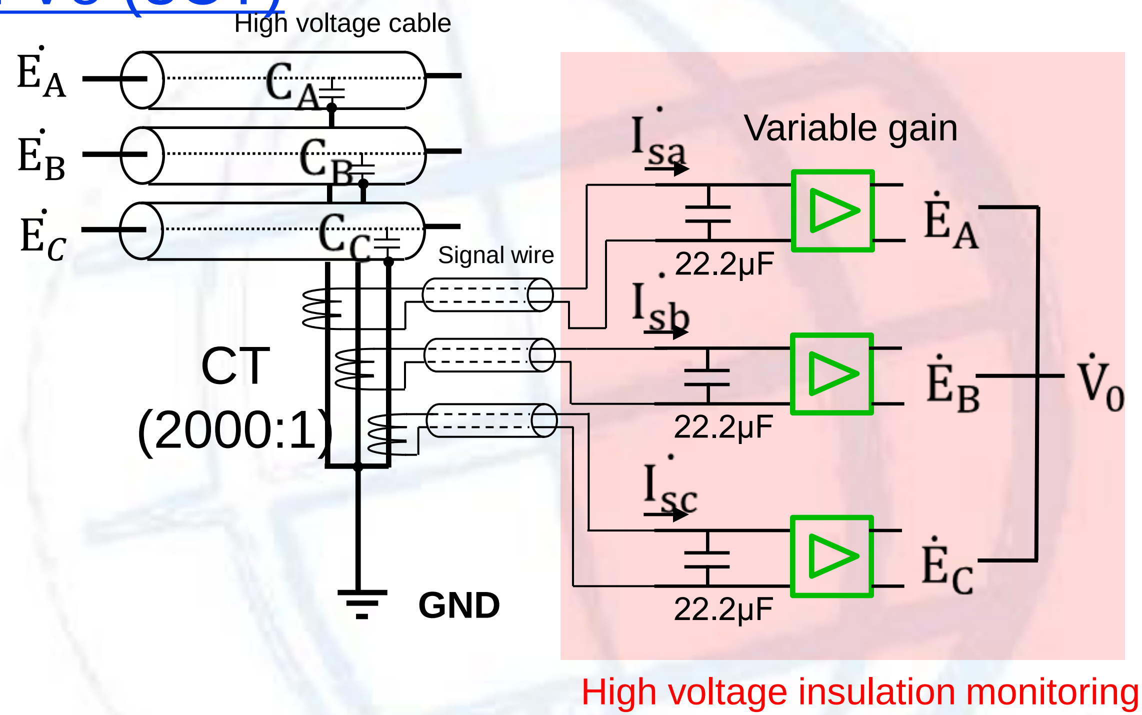
Vo is calculated by detecting the voltage to ground for each phase individually.

- Calculation of the voltage to ground of each phase

$$\dot{E}_A = \frac{\dot{I}_{sa} \times 2000}{j\omega C_A}$$

$$\dot{E}_B = \frac{\dot{I}_{sb} \times 2000}{j\omega C_B}$$

$$\dot{E}_C = \frac{\dot{I}_{sc} \times 2000}{j\omega C_C}$$



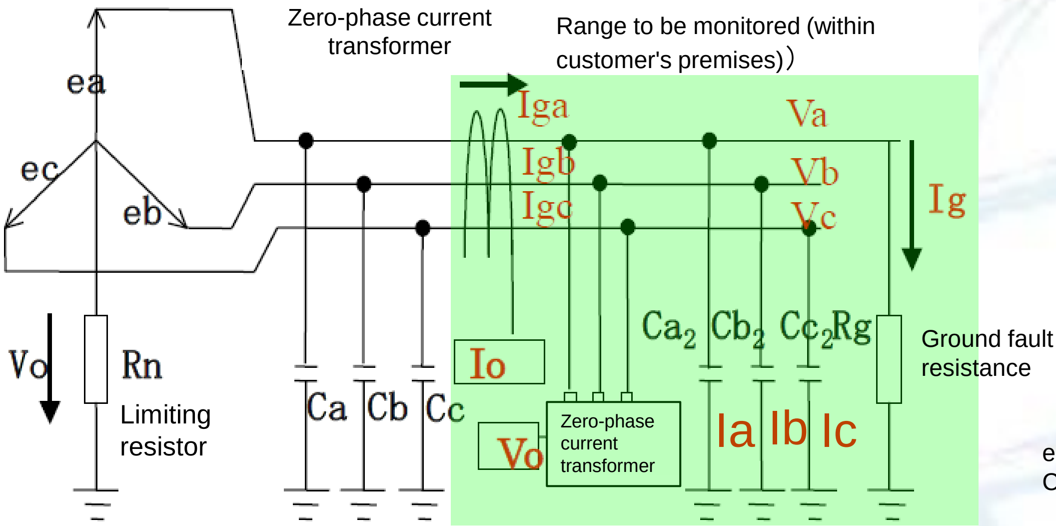
- Calculation of the zero-phase voltage (V_0)

$$\dot{V}_0 = \frac{\dot{E}_A + \dot{E}_B + \dot{E}_C}{3}$$

$\dot{I}_{sa}$、 $\dot{I}_{sb}$、 $\dot{I}_{sc}$: Shield current of each phase (CT secondary side)

C_A、 C_B、 C_C : Capacitance to ground of phase A, B, C

Principle of resistance ground fault (Rg monitoring)



In phase A of the electrical equipment in the premises, one line ground fault (ground fault at Rg) occurs and the ground fault current (Ig) has flown, the current detected by ZCT (Io) is:

Io=Ia+Ib+Ic+Ig ... (1)

The current in each phase is:

Ia=(ea - Vo)*jωCa2 ... (2)
Ib=(eb - Vo)*jωCb2 ... (3)
Ic=(ec - Vo)*jωCc2 ... (4)

ea, eb, ec	: Voltage to ground in each phase (ea + eb + ec = 0)
Ca, Cb, Cc	: Capacitance to ground in each phase outside the premises (distribution line side)
Ca2, Cb2, Cc2	: Capacitance to ground in each phase within the premises (in the power receiving equipment)

From (1) - (4), we obtain:

Io=(ea – Vo)*jωCa2+ (eb – Vo)*jωCb2+ (ec – Vo)*jωCc2+Ig
Io=Ig – Y*Vo + If ⇒ Ig=Io + Y*Vo – If … (6)

Y=jω(Ca2+Cb2+Cc2)
If=ea*jωCa2+eb*jωCb2+ec*jωCc2

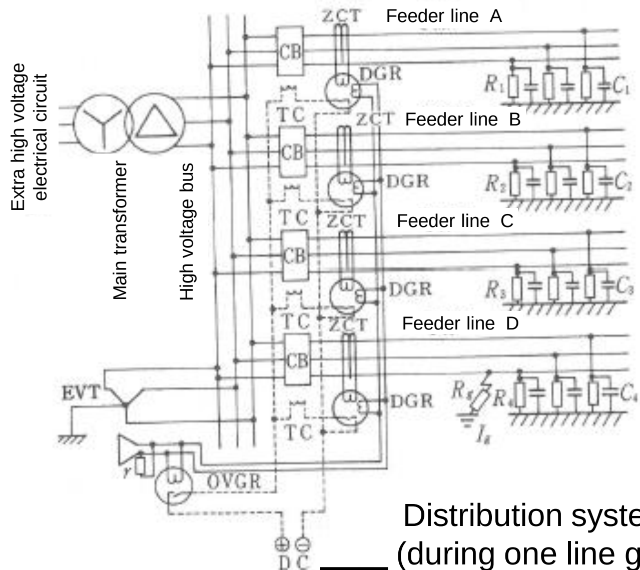
$$R_g = \frac{V_{Rg}}{I_g} = \frac{\sqrt{e_a^2 - V_0^2}}{I_g} = \frac{\sqrt{3810^2 - V_0^2}}{I_g} \ \ldots \ (7)$$

Current unrelated to insulation that is generated by imbalance of the premises capacitances to ground (Ca2, Cb2, Cc2)

Current unrelated to insulation that flows through the premises admittance to ground Y=ωC, due to Vo in the distribution line

An alarm goes off when it is detected that the value of Rg is equal to or below the set value for monitoring.

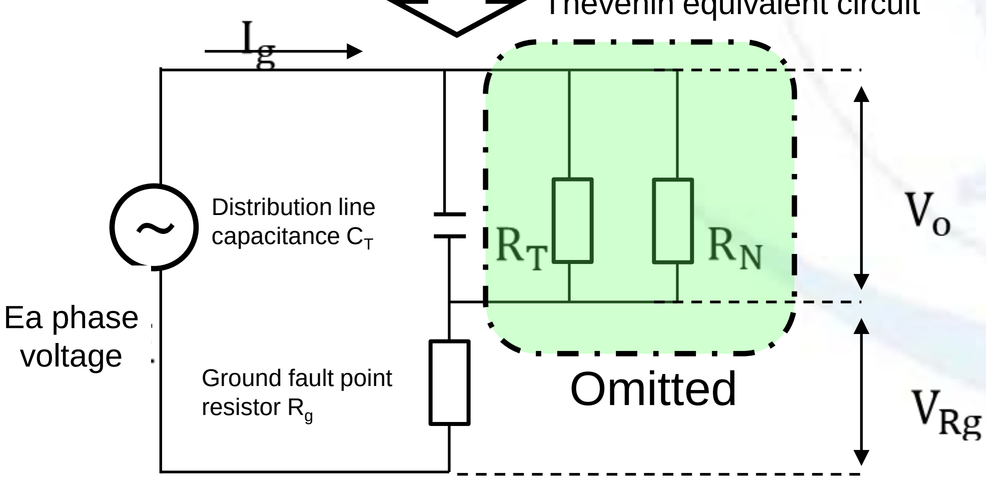
Principle of resistance ground fault (Rg monitoring)



CB: Circuit Breaker
TC: Trip Coil
DGR: Directional Ground Relay
OVGR: Over Voltage Ground Relay
ZCT: Zero-phase Current Transformer
EVT: Earthing Voltage Transformer
r: Limiting resistor
C: Capacitance of distribution line
Rg: Ground fault point resistance
Ig: Ground fault current
$R_1, R_2 \ldots R_n$: Leakage resistance to ground in one phase
$C_1, C_2 \ldots C_n$: Capacitance to ground in one phase

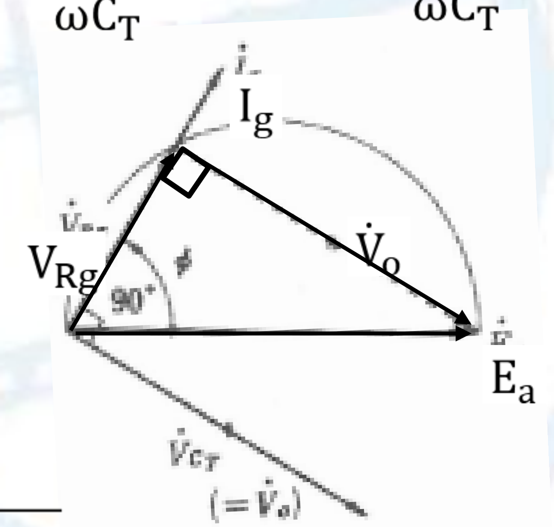
Distribution system diagram (during one line ground fault)

Thevenin equivalent circuit



Leakage resistor to ground: R_T and EVT limiting resistor (converted to primary): R_N are considered to have been omitted. Usually, they are as follows:

$$R_T \gg \frac{1}{\omega C_T} \qquad R_N \gg \frac{1}{\omega C_T}$$



$$V_{Rg} = \sqrt{E_a{}^2 - V_o{}^2}$$

E_a is the phase voltage (constant), and the magnitudes of V_{Rg} and V_0 can be divided at the point on the semi-circle of which diameter is E_a.

Cited from the High Voltage Power Receiving Equipment Regulations JEAC8011-2014

Principle of resistance ground fault (Rg monitoring)

Ig=Io + Y*Vo - If ... (6)

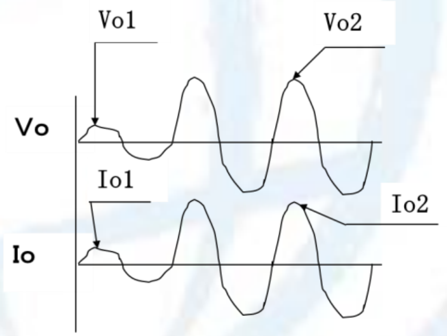
The second term in equation (6): Y*Vo is the current that outflows through the capacitance to ground in the premises due to Vo in the distribution line, which is unrelated to insulation.
The third term If in equation (6) does not include Vo, which is the current that flows without reference to the ground fault accident.
Since this is several mA or below, generally no emphasis is placed on it. However, in high voltage insulation monitoring, the current that should be detected is several dozens of mA, and so the influence of If cannot be disregarded.

Based on the foregoing, in high voltage monitoring, the second and third terms are obtained by the following method.
In the state without any ground fault, if Vo, Io are generated by an external factor, and when the former Vo1,Io1 have been changed to Vo2,Io2, since no ground fault has occurred, by assuming that Ig=0 in equation (6), the following can be obtained.

$$I_{01} = -Y \cdot V_{01} + I_f \cdots \quad (8)$$
$$I_{02} = -Y \cdot V_{02} + I_f \cdots \quad (9)$$

From (8) - (9), we obtain: $I_{01} - I_{02} = -Y \cdot (V_{01} - V_{02})$

$$\dot{Y} = \frac{-(I_{01} - I_{02})}{V_{01} - V_{02}} \text{、} \quad I_f = \frac{I_{02} \cdot V_{01} - I_{01} \cdot V_{02}}{V_{01} - V_{02}}$$



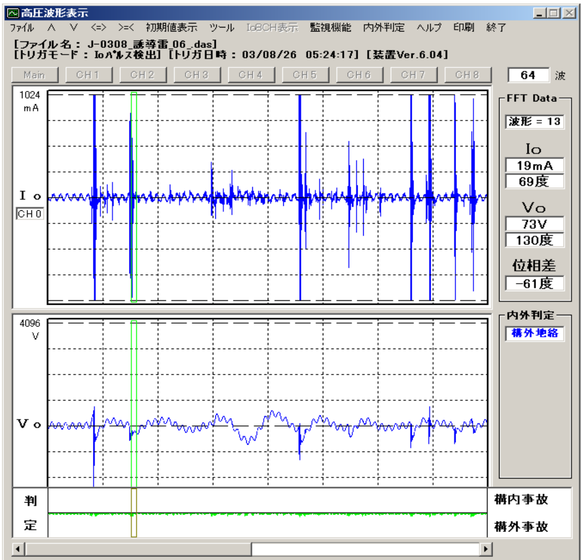
When residual components have been measured to be equal to or greater than the default values, Vo,Io at that time shall be used for the calculation.

Ground fault not affected by the residual components Ig = Io + Y･Vo - If

The second term Y and the third term If are called the premises constants, and when Vo fluctuations above a certain value have occurred, the monitoring system automatically measures and calculates the constants, and uses them as the fixed values inside the high voltage monitoring system.

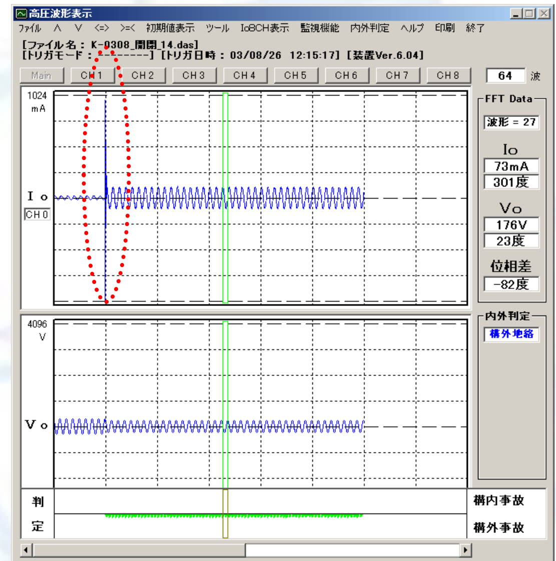
Abnormal waveform due to disturbances

Waveform of induced overvoltages due to nearby stroke



- Since random waveform is generated without reference to the power supply cycle, there is no periodicity, and the magnitude is also varied.
- When viewed by enlarging the time, triangular vibration waveform appears that resembles that with the high voltage cable.

Waveform of a switching surge



- Pulsed waveform in an extremely short period of time around 1/8 can be seen, and then the waveform returns to normal one.
- In the example shown above, before and after the switching waveform, increases in capacitance can be seen.

The cause can also be estimated based on information such as meteorological information (lightning) and interviewing the customer (operation of the high voltage circuit).