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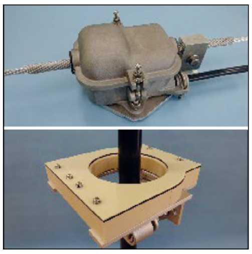

Full-Scale Delivery of Fault Sector System for Overhead/Underground Transmission Lines

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Stable electric power supply is vital for today's society. However, line faults still occur because of lightning strikes or other causes. Line faults must be located and repaired as quickly as possible. In particular, in the case of line faults where overhead and underground transmission lines are connected, recovery measures differ by location. Thus, locating the line fault and determining whether the line fault is on the overhead or underground transmission lines is critical for early recovery. We have developed the Fault Sector System that identify line faults based on the information from current sensors installed on overhead ground wires and underground power cables. This system has been fully implemented in electric power companies. This paper reports on the outline of the system.

Keywords: fault location system, CT, Rogowski coil, determination of overhead/underground line faults

1. Introduction

With the development of an advanced information society, a stable supply of electric power has become increasingly important. However, transmission line faults caused by lightning and other causes have not been eliminated. In the event of a transmission line fault, it is necessary to identify the fault location quickly and efficiently and implement restoration measures.

At Sumitomo Electric Industries, Ltd., we have delivered fault location (FL)*[1] systems to electric power companies to monitor overhead transmission lines. These FL systems have been operated on more than 300 lines. They are effectively utilized for maintenance of transmission lines, such as identification of locations of transmission line faults due to lightning and other causes.

In terms of transmission line configurations, some consist only of overhead lines, but others consist of both overhead and underground lines. In the event of a transmission line fault on the latter lines, different methods must be used for fault restoration. Thus, it is important to judge whether an FL is on the overhead or underground line to achieve quick restoration.

We have developed a "fault sector system for overhead and underground transmission lines," in which a current sensor is installed on an overhead ground wire*[2] and underground line to judge faults on the overhead and underground lines based on the current information. The system has been delivered to electric power companies on a full scale. This paper presents an overview of the system.

2. Overview of the Fault Sector System for Overhead/Underground Transmission Lines

The fault sector system for overhead and underground transmission lines is available in two types: an overhead sensor system and an underground sensor system. They are selected depending on the line to which the system is applied and the configuration of steel towers. The basic configurations of the systems are shown in Fig. 1.

① Overhead sensor system

An overhead sensor (current transformer: CT*[3]) for detecting the current of an overhead ground wire is installed at two locations: an underground line separation tower and an adjacent steel tower (5 to 10 towers away from the tower that branch off the underground line). The

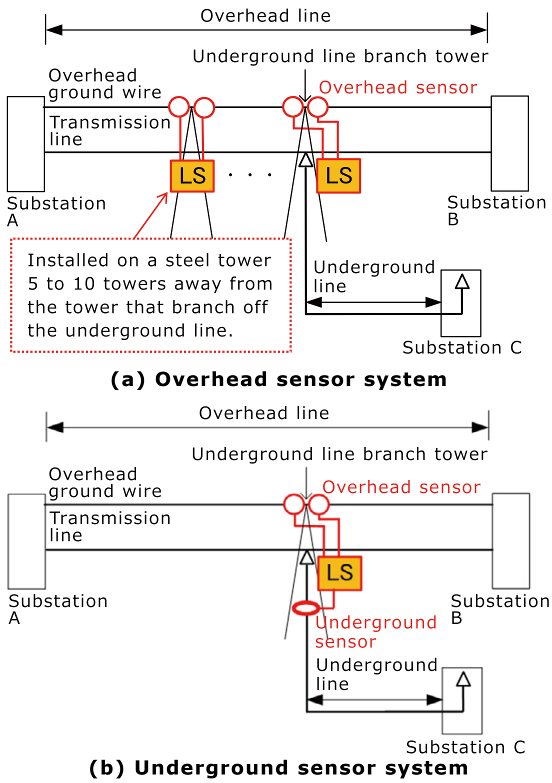

Fig. 1. Basic configuration of the system

system detects a current that flows through an overhead ground wire in the event of a transmission line fault.

The system is applied to a line which has an overhead ground wire, through which a current flows in the event of a transmission line fault. Specifically, it is used for a transmission line of 66 kV or more with neutral point grounding.*4

② Underground sensor system

At an underground line branch tower, an overhead sensor is installed on an overhead ground wire, and an underground sensor (Rogowski coil*5) is installed on each phase of a three-phase conductor of an underground line to detect a current that flows through the overhead ground wire and underground line in the event of a transmission line fault.

Only an underground sensor can be applied if an overhead sensor cannot be applied to a line in which no current flows through an overhead ground wire in the event of a transmission line fault (e.g., a transmission line whose voltage is less than 66 kV and neutral point is grounded with high resistance) and a steel tower without an overhead ground wire.[1]

For a line whose underground line length is 2 km or more, an underground sensor may be installed at both ends of the underground line.

3. Overhead Sensor System

3-1 Configuration

Figure 2 shows the equipment layout and system configuration. The sensors and equipment of the FL equipment are used.

(1) Overhead sensor

An overhead sensor is installed on an overhead ground wire of a steel tower. The output corresponding to the current of an overhead ground wire is transmitted to the Local Station (LS), which is installed in the lower part of the steel tower.

The number of sensors depends on the number of overhead ground wires. For example, when there is one overhead ground wire, two sensors are installed in total, one each upstream and downstream of a steel tower.

The sensors are installed using dedicated tool. Specifically, they are directly held and secured to an overhead ground wire.

(2) Local Station

The LS constantly monitors the current of an overhead ground wire, which is detected by a sensor. Faults are judged and detected based on the current intensity and the fault continuing cycle, among other factors.

The current information in the event of a transmission line fault is transmitted to the Master Station (MS) via a communication line. For the communication method, emails are sent via a packet network of mobile phones and the Internet.

No power supply is needed from the distribution line because a solar panel and a battery are used as the power supply.

(3) Master Station

A PC equipped with a general-purpose CPU and running on a general-purpose OS is used as the MS. With fault judgment software installed, the MS judges faults on the overhead and underground lines based on the current information in the event of a transmission line fault sent from the steel tower.

3-2 Functions and specifications

The functions and specifications of an overhead sensor system are shown in Table 1. The CT sensor that constitutes the overhead sensor has a bisection structure so that it can be installed on the overhead ground wire.

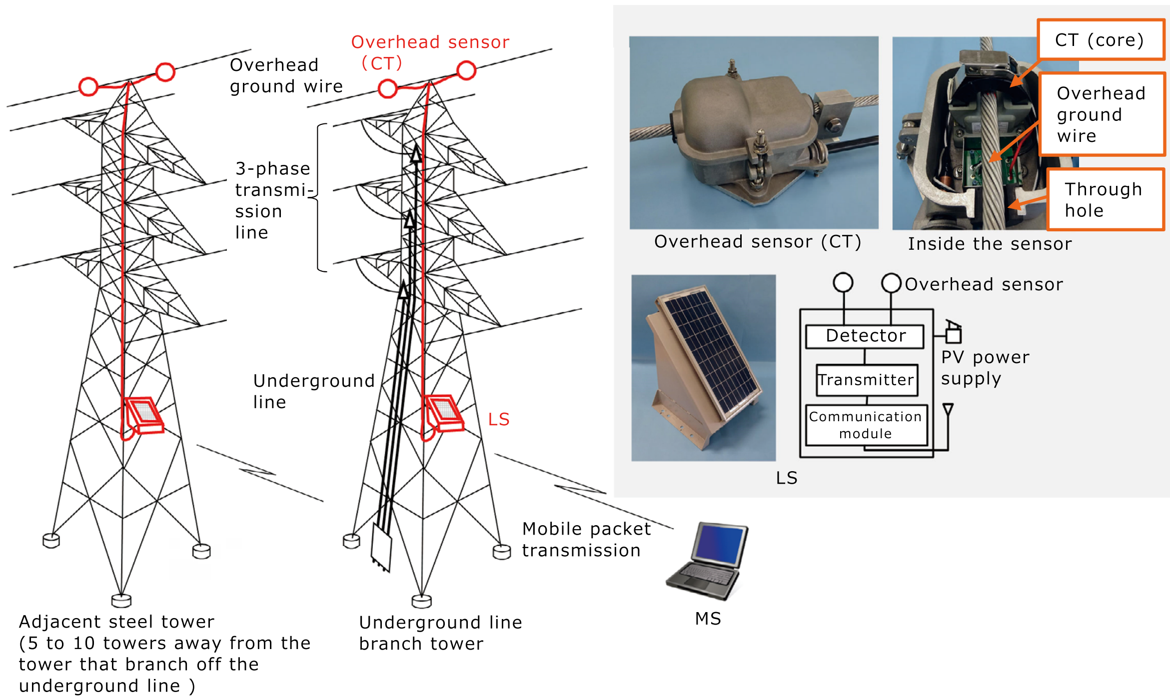

Fig. 2. Equipment layout and system configuration (overhead sensor system)

Table 1. Functions and specifications (overhead sensor system)

Item		Functions and specifications
Overhead sensor	Type	2-Split-type CT (core material: ferrite)
	Through hole	Approx. 35 mm or less
	Detectable current	500 A/1,000 A/15,000 A or less (for each range)
Local Station	Sensor input	4ch
	Function	Memory: 16 fault detection results are recorded.
		Self-diagnosis: Abnormalities in the internal circuit, time, etc.
		Power supply monitoring: The power supply voltage is monitored.
	Communication method	Mobile packet transmission method (LTE)
	Power supply	Solar panel: 12 V–14 W × 1
		Battery: 12 V–38 Ah × 1
Master Station	Specifications	PC equipped with a general-purpose CPU and running on a general-purpose OS
	Function	• Fault judgment processing for overhead/underground lines • Display of fault judgment results on the screen

The LS has four sensor inputs, enabling connection of up to four overhead sensors.

3-3 Fault judgment process

The fault current information obtained by overhead sensors and transmitted from a steel tower is checked against the simulation results using the Electromagnetic Transients Program (EMTP) to detect a sector whose current distribution matches as a fault sector.

Overhead and underground line faults are judged based on the detection results. A neural network is used to check against the simulation results. The flow of the fault judgment process is shown in Fig. 3.

In the overhead sensor system, an overhead sensor is installed at two locations: an underground line branch tower and an adjacent steel tower (5 to 10 towers away from the tower that branch off the underground line). The current information is used to judge faults on the overhead and underground lines.

Here, the necessity to install an overhead sensor at the two locations is discussed using the simulation results of

Table 2. Simulation conditions for Fig. 4

Item	Details
Line configuration	An overhead line with 30 steel towers, with its underground line being branched at steel tower No. 15 (in the middle) (Fig. 4 (a))
Overhead line fault	Fault location: Steel tower No. 12 The value of a current which flows through the overhead ground wire in the event of a transmission line fault at steel tower No. 12 is calculated for each steel tower (Fig. 4 (b) —○—).
Underground line fault	Fault location: An underground line which is branched from steel tower No. 15 The value of a current which flows through the overhead ground wire in the event of an underground line fault is calculated for each steel tower (Fig. 4 (b) —■—).

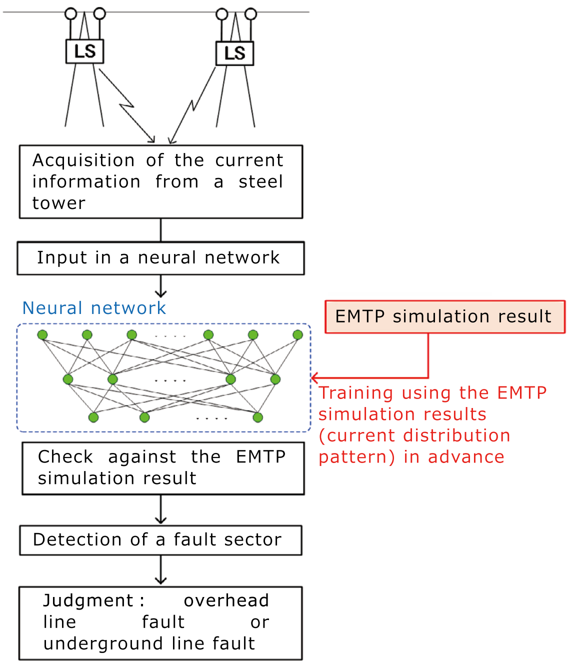

Fig. 3. Flow of the fault judgment process (overhead sensor system)

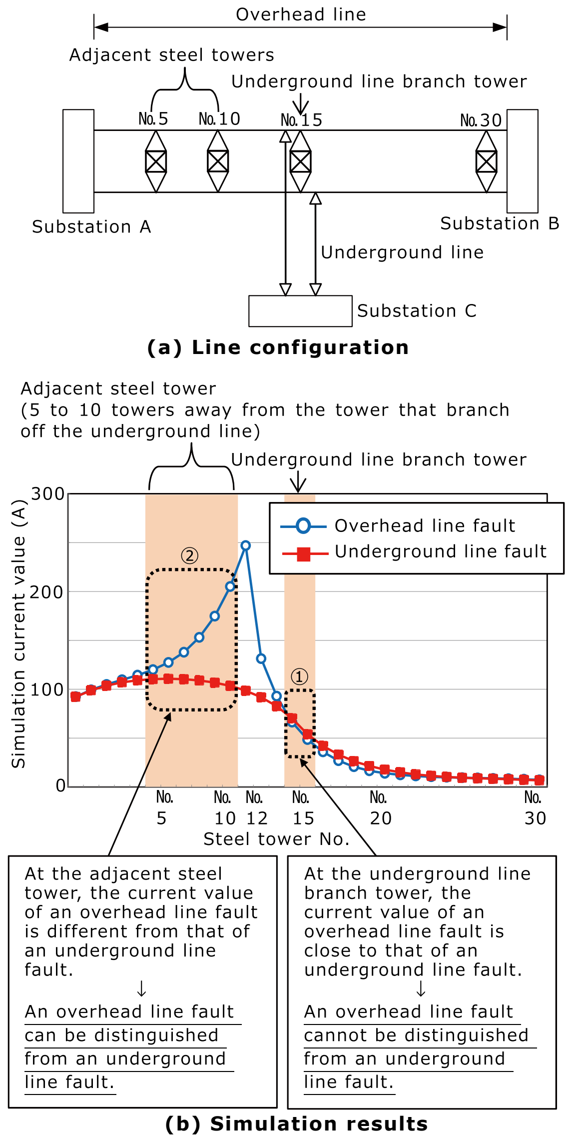

Fig. 4. Example of simulation results

Fig. 4 as an example. The simulation conditions are shown in Table 2.

At steel tower No. 15, where the underground line is branched, the current value of an overhead line fault is close to that of an underground line fault, as shown in Fig. 4 (b) ①. Thus, an overhead line fault cannot be distinguished from an underground line fault.

Meanwhile, at steel towers No. 5 to No. 10, which are adjacent steel towers 5 to 10 towers away from the tower that branch off the underground line, the current value of an overhead line fault is different from that of an underground line fault (see Fig. 4 (b) ②), making it possible to distinguish an overhead line fault from an underground line fault.

Thus, if an overhead sensor is installed only on an underground line branch tower, it may not be possible to judge an overhead or underground line fault. By adding an overhead sensor to adjacent tower and comparing the current values at two locations, the simulation results of the overhead line fault current and the underground line current differ at least one location. Therefore, it is possible to identify the fault sector by comparing the measured current value from the overhead sensor with the simulation result.

4. Underground Sensor System

4-1 Configuration

Figure 5 shows the equipment layout and system configuration. An underground sensor is installed on each phase of a three-phase conductor. The sensors are connected to an input unit through three-phase detection current synthesis and two-line detection current synthesis in a repeater box or the LS box.

The output voltage of underground sensors is small because Rogowski coils are used. Thus, the signals are amplified by the input unit before they are input into the LS.

The number of underground sensors depends on the configuration of an underground line. For example, in the case of a single-core XLPE cable,*6 three sensors are installed on each line. In the case of a XLPE triplex cable*7 (a strand of three single-core cables), one sensor is installed on each line.

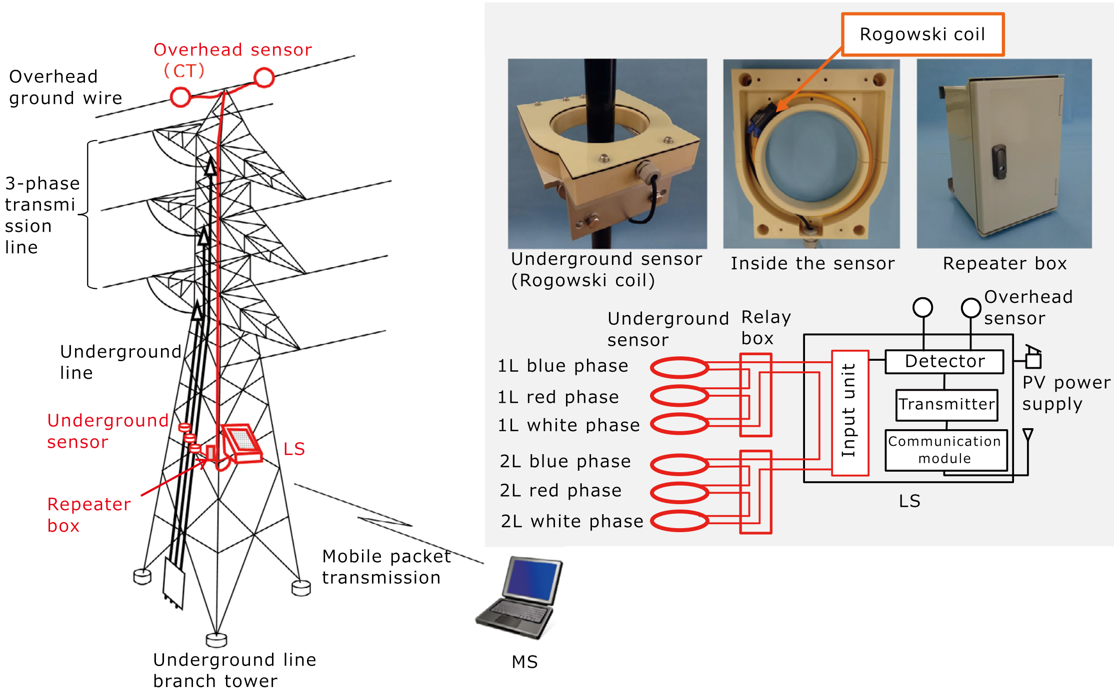

Fig. 5. Equipment layout and system configuration (underground sensor system)

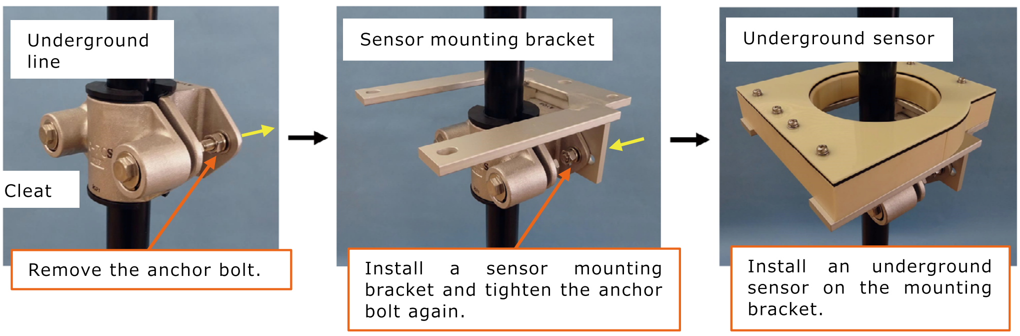

Fig. 6. Method of installing an underground sensor

Underground sensors are secured to a steel tower member by using existing cleats that hold the underground lines. They are not directly installed on the underground lines and can be secured without applying an excessive load or causing damage to the underground lines. They can also be installed under the live line condition because the output voltage of the sensors is small and there is no risk of getting an electric shock. The method of installing an underground sensor is indicated in Fig. 6.

A repeater box is installed near underground sensors and is secured to a steel tower member using stainless steel bands. The LS is the same as that of the overhead sensor system, and the input unit for underground sensors is stored in the LS box.

4-2 Functions and specifications

The functions and specifications of an underground sensor, a repeater box, and an input unit are shown in Table 3.

Table 3. Functions and specifications (underground sensor, relay box, input unit)

Item		Functions and specifications	
Underground sensor	Type	Rogowski coil	
	Applicable cable diameter	Approx. 140 mm or less	
	Detectable current	40 A/500 A or less (for each range)	
Repeater box	Material	Polycarbonate	
	Waterproof performance	IP65	
Input unit	Sensor input	1ch	
	Measurement range	40 A range	500 A range
	Input level	0 ~ 5 mV	0 ~ 60 mV
	Output level	0 ~ 5 V	0 ~ 5 V

4-3 Fault judgment process

Underground sensors which are installed on each phase constantly detect a current equivalent to up to several hundred amperes. As the phases are balanced, the current value of three-phase synthesis and two-line synthesis is approximately 0 A. In the event of an underground line fault, the phases are imbalanced, resulting in significant changes in the current value of three-phase synthesis and two-line synthesis.

This working principle is used to perform thresholding of detected current values of underground sensors to judge underground line faults. Thresholds are set in advance by conducting a simulation for each line to be applied. Fault sector detection results of overhead sensors are also added to judge faults on the overhead and underground lines. The flow of the fault judgment process is shown in Fig. 7.

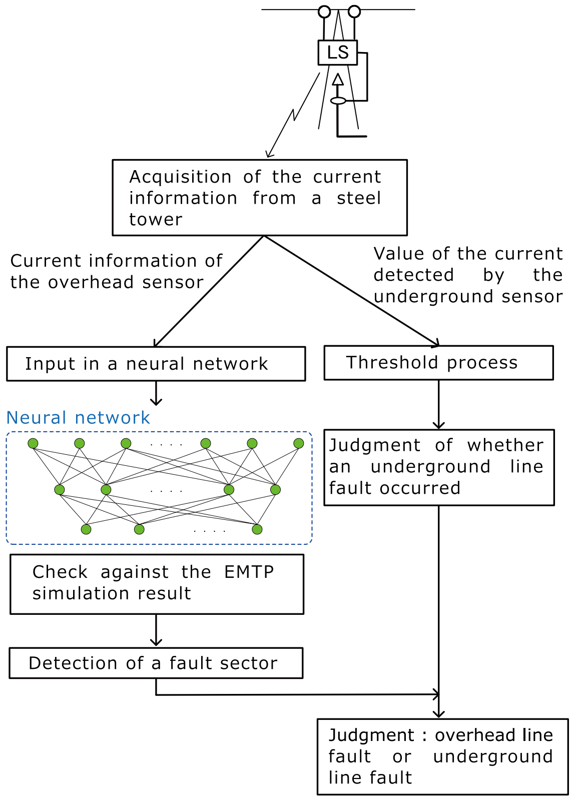

Fig. 7. Flow of the fault judgment process (underground sensor system)

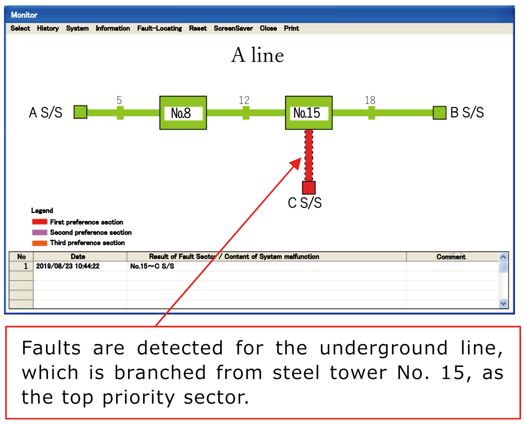

Fig. 8. Example of a screen display on the Master Station

These systems have detected and correctly located overhead and underground line faults. Figure 8 shows an example of a screen display on the MS when an underground line fault is detected.

5. Effectiveness of the System

Regarding the operation of the fault sector system for overhead and underground transmission lines, the overhead sensor system is operated on more than 100 steel towers where the underground line is branched, while the underground sensor system is operated on several such steel towers.

6. Conclusion

As the fault sector system for overhead and underground transmission lines, we have developed two types of systems, one using overhead sensors and the other using underground sensors, based on FL technology and have delivered them to electric power companies on a full scale.

These systems in operation on actual lines have a track record in correctly judging faults on overhead and underground lines. They have been effectively utilized for maintenance of transmission lines.

Technical Terms

∗1 Fault location (FL) system: A system for identifying a fault location caused by lightning and other causes on an overhead transmission line. Our system uses a CT to detect a fault current that flows through an overhead ground wire.

∗2 Overhead ground wire: A ground wire which is strung on steel towers for lightning protection and shielding. It is laid at the top of transmission lines to serve as lightning protection equipment, which protects transmission lines (electric power lines) from direct lightning strikes.

∗3 Current transformer (CT): A current sensor for measuring the alternating current by detecting changes in the magnetic field, which are caused by a current, using a magnetic core.

∗4 Neutral point grounding: To ground the electrically neutral point of a generator or transformer (common connection point in each phase of star (Y) connection) on a three-phase AC transmission line. There are mainly two types of systems. One is to ground the neutral point directly to a conductor, and the other is to ground the neutral point to a resistor.

∗5 Rogowski coil: A current sensor which performs measurement by converting the voltage induced in the air-core coil. It does not use a magnetic core to detect an AC magnetic field.

∗6 XLPE cable: Cross-linked polyethylene insulated vinyl sheathed cable. This is one type of electric power cable. Its conductors are clad with cross-linked polyethylene, and the circumference is clad with a vinyl sheath.

∗7 XLPE triplex cable: Cross-linked polyethylene insulated vinyl sheathed triplex cable. This is one type of multicore XLPE cable incorporating three strands of XLPE cables.

Reference

(1) K. Sakurai, T. Imagawa, T. Matsushita, O. Sakai, "Development of fault sector (Overhead/Underground power line)," IEEJ Power and Energy Society Conference (2012)

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