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Sensor Transmission-Based Overload Relay System for Enabling Monitoring of Transmission Line Bottleneck Locations

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To achieve carbon neutrality, efforts are being made to establish renewable energy as the primary power source. However, a significant challenge is the inability to connect renewable energy sources due to insufficient transmission capacity in overhead transmission lines. To address this issue, the N-1 contingency for electricity transmission has been implemented since 2022, utilizing existing infrastructure to its maximum potential. The N-1 control system allows electricity that becomes unavailable due to transmission line accidents to flow to other operational lines, which can lead to those lines becoming overloaded. To mitigate this, the output of some power sources is reduced. In this context, we have developed and put into practical use a sensor-based Over Load Relay (OLR) system that utilizes our transmission line sensors, enabling near-real-time current measurements.

Keywords: renewable energy, overhead transmission lines, Over Load Relay (OLR), N-1 control system

1. Introduction

Efforts are underway to establish renewable energy (RE) as a primary power source to achieve carbon neutrality.

The recent increase in RE has led to insufficient transmission capacity on overhead transmission lines, which has made connecting new power sources using conventional operational methods challenging. Options for connecting new power sources to transmission lines with insufficient capacity—such as increasing conductor size or adding new lines—require significant cost and time.

To address this issue, the application of an operational method, "N-1 control system," which maximizes the use of existing facilities, began in July 2022.

The N-1 control system is a mechanism that allows power sources to be connected to transmission lines under the condition that, when current cannot be transmitted due to accidents at transmission and substation facilities, causing current to be diverted to healthy transmission lines and exceeding their capacity (overload), the Over Load Relay (OLR) system limits power generation output. This enables the expansion of transmission capacity during normal operation.

We introduce a sensor-transmission type OLR system we have developed and put into practical use. This system utilizes our transmission line sensors, capable of real-time current measurement at intervals of 5 seconds, as the current measuring instruments for detecting the OLR system's overload current.

2. Challenges and Solutions for Overloaded Section Detection

This section considers a transmission network with two transmission lines, as shown in Fig. 1, where new power sources, including RE, have been added. Initially, as shown in Fig. 1 (a), the transmission lines were designed and operated so that even if one line failed, the transmission lines would not become overloaded. However, with new power sources connected midway along the transmission lines, cases have emerged where overloads occur in intermediate sections of the transmission lines, as shown in Fig. 1 (b). With the increased introduction of RE, output fluctuates significantly due to weather conditions, causing transmission currents to vary greatly by season and time of day. Therefore, real-time monitoring of transmission currents is necessary to prevent overloading in intermediate sections of transmission lines.

A multi-terminal transmission-type OLR has been put into practical use as a method for detecting current values in intermediate sections. This system involves installing current measurement terminals on all power sources and loads connected to the transmission network, then calculating the current in the transmission line section from the

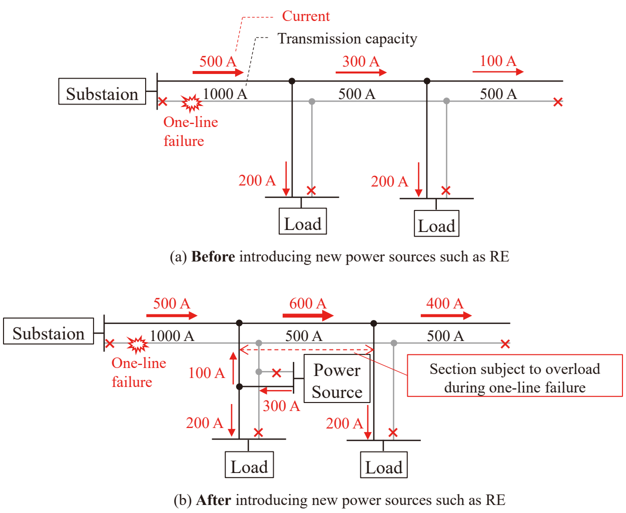

Fig. 1. Schematic of current flowing through intermediate sections of the transmission lines

respective current values. The multi-terminal transmission-type OLR requires installing current measurement terminals on all power sources and loads to determine the transmission current for one or two sections, presenting challenges in terms of cost and time.

The newly developed sensor transmission-type OLR system employs a method where sensors are attached to transmission lines in the overloaded section to measure current. This allows direct monitoring of the overloaded section, thereby eliminating the need for current measurement terminals for new power sources and similar equipment.

3. Transmission Line Sensor-Based OLR system

The Sensor Transmission OLR System consists of transmission line sensors, repeaters, integrators, OLR equipments, and terminal devices (Fig. 2). Transmission line sensors are installed on the overloaded section to measure the transmitted current.

The measured current is transmitted wirelessly to the integrator and then via optical fiber to the OLR equipment installed at the substation. The OLR equipment transmits a suppression signal to the terminal device when the transmitted current exceeds the transmission capacity. This signal suppresses power generation, reducing the transmitted current to below the transmission capacity. In this system, our company was responsible for the transmission line sensors, repeaters, and integrators.

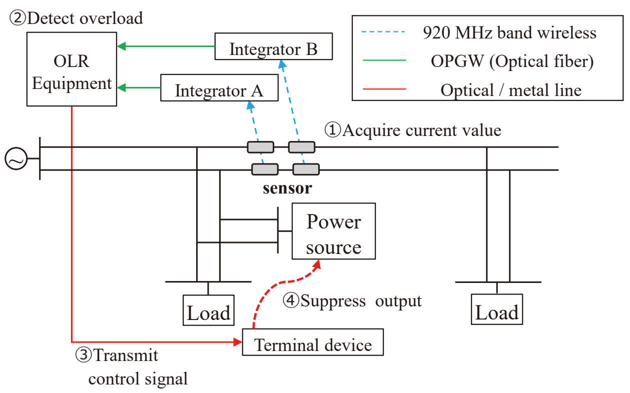

Fig. 2. Overview of sensor transmission OLR system

For wireless transmission between the transmission line sensors and the integrator, a multi-hop communication function*[1] was adopted, enabling transmission along linear, long-distance facilities like transmission lines through multi-stage relaying (Fig. 3).

Furthermore, the 920 MHz band wireless used here constitutes a proprietary communication network that does not utilize public lines. This enables communication even in mountainous areas outside the service areas of telecommunications carriers. Additionally, the content of the wireless data is kept confidential as our proprietary specification and is further encrypted. This reduces the risk of intentional malfunction caused by information leaks or data interception.

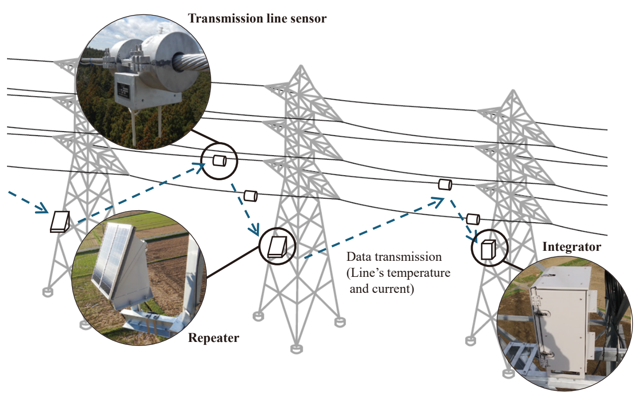

Fig. 3. Overview of our system

The transmission line sensors measure the current and temperature of the transmission lines and transmit this data wirelessly to the integrator. To ensure redundancy,*[2] two transmission line sensors are installed on each line.

Repeaters are used when the integrator cannot communicate wirelessly with the transmission line sensors. By installing a repeater between the transmission line sensors and the integrator, it becomes possible to relay the transmission line sensor data and transmit it to the integrator.

The integrator is installed atop transmission towers. It converts the data received wirelessly from the transmission line sensors into optical signals using a media converter,*[3] and then transmits this data via the optical fiber in the optical fiber composite overhead ground wire (OPGW) to the OLR equipment within the substation.

The OLR equipment uses the current data sent from the integrator to determine transmission line overload and control power generation. Tokyo Densetsu Service Co., Ltd. was responsible for the OLR equipment.

4. Various Equipment

4-1 Transmission line sensor

Photo 1 shows the appearance of the transmission line sensor. This sensor can measure both the current and the temperature of the transmission line.

Since this sensor is directly mounted on high-voltage transmission lines, providing external power is difficult. Therefore, it employs an electromagnetic induction method that operates on the current from the transmission line.

Electromagnetic induction is used to measure current, while a temperature probe*[4] is employed for temperature measurement, which prioritizes accuracy.

When the current falls below the lower limit of the measurement range, the power obtained by electromagnetic induction also decreases. To prevent the equipment from starting up in this state, it monitors the obtained power and incorporates a function to control the start-up based on this, thereby enhancing the stability of the transmission line sensor and the entire system.

Photo 1. Appearance of transmission line sensor

Table 1. Main specifications of the transmission line sensor

Item		Specifications
overview	Applicable cable size	ACSR160 ~ 810 mm^2
	Dimensions	282×252×225 mm
	Weight	Approx. 13 kg
	Transmission cycle	5 seconds
	Radio frequency	920 MHz
	Wireless transmission distance	≥ 1 km in line-of-sight conditions
Current measurement	Measurement range	50~1200 A
	Measurement error	±3%
Temperature measurement	Measurement range	-20 ~ 120°C
	Measurement error	±2°C

4-2 Repeater

Photo 2 shows the appearance of the repeater. The repeater is installed at the base of the transmission tower and is powered by an independent power supply consisting of solar panels and batteries.

While the wireless transmission range of the transmission line sensor is at least 1 km in line-of-sight conditions, installing a repeater on transmission towers along the line enables wireless multi-hop communication. This allows for data transmission to distant integrators.

Photo 2. Appearance of the repeater

4-3 Integrator

The appearance of the integrator is shown in Photo 3. The integrator is installed inside the transmission tower and powered by an independent power supply consisting of solar panels and batteries.

The integrator receives data transmitted from the power line sensors and converts it into a GOOSE*5 format, which is an international standard protocol. Furthermore, since communication between the integrator and the OLR equipment uses OPGW, an optical media converter is used to convert the electrical signal into an optical signal for transmission. Even if OPGW is unavailable, the integrator can transmit data wirelessly using mobile communication networks.

Photo 3. Appearance of the integrator

5. Redundancy

Figure 4 illustrates the information transmission route. Two sensors are installed on each transmission line. Sensor A and Sensor B transmit information to integrator A and integrator B, respectively, creating a redundant configuration for communication between the sensors and the integrators. In the case of a typical two-circuit transmission line, sensors are installed on both the 1L and 2L lines. Integrator A handles the transmission of information from Sensor A_{1L} and Sensor A_{2L}, while integrator B handles the transmission of information from Sensor B_{1L} and Sensor B_{2L}.

The integrator installed on the tower and the OLR equipment installed at the substation are connected via OPGW optical fiber cable. Considering potential OPGW communication failures, integrator A and integrator B are routed separately, thus creating a redundant configuration as well.

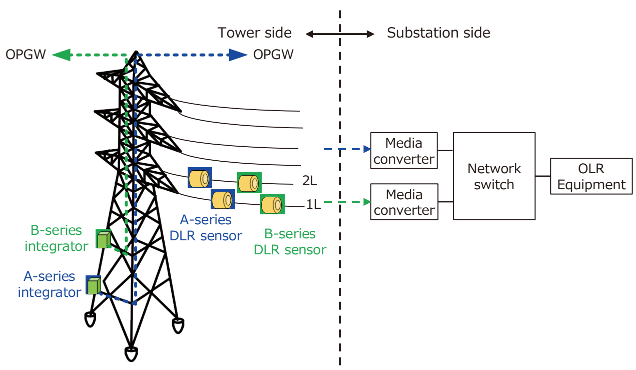

Fig. 4. Redundancy concept

6. Data Transmission

Data transmission utilizes IEC 61850 GOOSE, which is an internationally standardized protocol widely adopted for the automation of power equipment operations. The following describes data transmission from Sensor A.

The integrator transmits the current value information received from the sensors every 5 seconds to the OLR equipment via GOOSE. Since the timing for transmitting data from the sensors to the integrator differs between Sensor A_{1L} and Sensor A_{2L}, the following processing is performed to send the GOOSE signal to the OLR equipment.

Figure 5 shows the processing method. The integrator transmits data when it receives the current value from Sensor A_{1L}. However, at that timing, it has not yet received the current value from Sensor A_{2L}, so it transmits a value of −99999 instead for Sensor A_{2L}. Similarly, when receiving the current value from Sensor A_{2L}, it transmits a value of −99999 instead for Sensor A_{1L}.

Furthermore, since the sensors are driven by electromagnetic induction from the transmission line current, if the current is too low, the sensors will not activate and cannot transmit a current value. Therefore, if the state where no current value is received from the sensors persists for 30 seconds, the current value is transmitted to the OLR equipment as −99999.

Separate from the OLR equipment, a system management server for data storage and verification is also installed to accumulate and analyze collected data (Fig. 6).

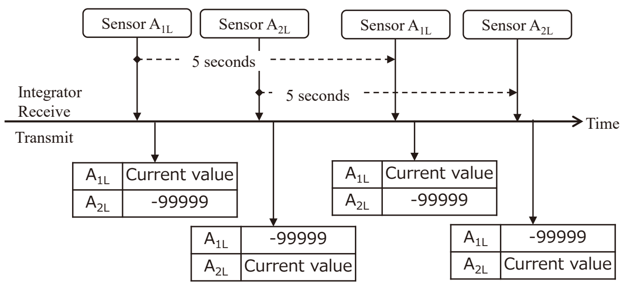

Fig. 5. Transmission of current information

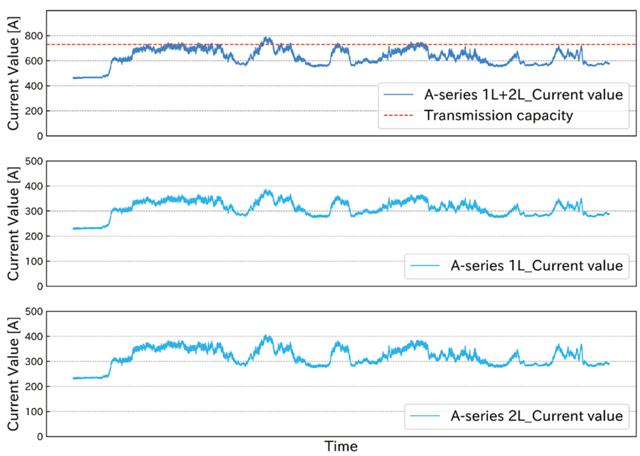

Fig. 6. Example of transmission line current value data

Since the transmission capacity of this transmission line is approximately 730 A, data analysis reveals that if a problem occurs in 1L and power is supplied only through 2L, the transmission capacity will be exceeded, necessitating OLR.

7. Conclusion

This paper describes our sensor transmission OLR system using our transmission line sensors. The sensor transmission OLR system that we developed commenced operation on a 66 kV transmission line of Tokyo Electric Power Company Grid in May 2023. To support carbon neutrality and the introduction of RE initiatives, we plan to address various needs, including this transmission line sensor for OLR systems, dynamic rating,*6 and transmission line degradation diagnosis.

8. Acknowledgments

Finally, in the formulation of the specifications for this system, we would like to express our sincere gratitude to the personnel at TEPCO Power Grid Co., Ltd. and Tokyo Electric Construction Service Co., Ltd. for their extensive guidance and advice.

Technical Terms

*1 Multi-hop communication function: A technology that enables wide-area communication by allowing multiple wireless terminals to relay data to adjacent terminals, with information transmitted similar to a bucket brigade.

*2 Redundancy: Duplicating the entire system, including the network, and establishing a backup system to enhance fault tolerance.

*3 Media converter: A network device that converts signals between different communication media (e.g., electrical signals in LANs and optical signals in optical fiber).

*4 Temperature probe: A sensor component that detects temperature by making contact with the object being measured, located away from the main body of the thermometer. This sensor uses a thermocouple.

*5 GOOSE: An abbreviation for Genetic Object-Oriented Substation Events. One of the communication protocols defined in IEC 61850.

*6 Dynamic rating: A technology that monitors transmission line temperatures in real time and dynamically controls transmission capacity according to weather conditions.

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