Overhead Transmission Line Monitoring System for Dynamic Rating

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With an increase in the use of renewable energy, the problem of power system constraints in which electricity transmission is limited has become significant. One major factor of this is the restricted capacity of transmission lines. While the enhancement of the transmission line capacity is necessary to solve this problem, it requires a large amount of capital and time. Therefore, it is important to utilize existing systems to their maximum potential. For the purpose of increasing power transmission capacity of existing systems, we have been developing a real-time monitoring system for the temperature and electric current value of power transmission lines. This paper reports on the present status of our ongoing developments.

Keywords: dynamic rating, multi-hop communication, self-powering

1. Introduction

In Japan, the share of renewable energy (including hydropower) in total electricity generation in fiscal 2011 was 10.6%, which increased to 15.3% in fiscal 2016 and is expected to reach between 22% and 24% in 2030. Existing power grid systems are designed to connect strategically constructed power stations and demand area and are not designed to transmit electricity generated by renewably energy from dispersed sources. Consequently, along with the growth of renewable energy, the insufficient transmission capacity of the grid has become an emerging issue. When connecting new power sources, the grid can accept them on a first-come, first-served basis if it has spare transmission capacity. If does not, the grid may reject new power sources or its current-carrying capacity needs to be enhanced. Meanwhile, some European countries have introduced a program to allow for connections under certain conditions, making maximum use of the existing grid.[(5)-(10)]

We usually consider replacing with larger overhead transmission lines or installing additional channels for boosting grid capacity, but it requires much cost and time, so it is important to use the existing grid with maximum efficiency. In recent years, there have been discussions in Japan on schemes to make flexible use of spare grid capacity and authorize connections to the grid subject to certain restrictions.[(5)-(10)]

Currently, the capacity of an overhead transmission line is determined as the allowable current at which the conductor in use will not exceed its temperature rating under constant environmental air conditions of a temperature of 40°C, wind speed of 0.5 m/s, and insolation of 1,000 W/m^2, as shown in Fig. 1. These environmental conditions are those under which the temperature of conductors could reach a maximum. Therefore, under normal operating conditions, the conductor temperature is likely to be below it. Based on this idea, it has been proposed to operate overhead transmission lines according to their real capacity determined by a dynamic rating system.[(3),(4)] Dynamic rating means dynamically changing the capacity rating of a transmission line by measuring its temperature and current value in real time. Sumitomo Electric Industries, Ltd. has developed an overhead transmission line monitoring system for the management of transmission line capacity and its dynamic control in the future. This paper outlines the system and reports on the current state of development and future prospects.

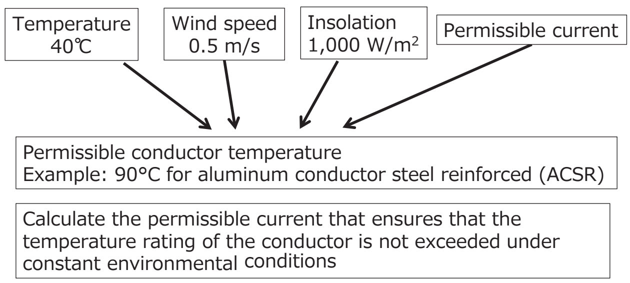


Fig. 1. Determination process for transmission line allowable current

2. Overview of Dynamic Rating System

2-1 Method considerations

As reported in demonstration examples in other countries, the sensed parameters in the dynamic rating is the temperature of the conductor as well as its tension and angle of inclination, which change as the conductor expands or contracts with temperature. Table 1 compares sensed parameters. Based on this comparison, we decided to use the method of directly measuring the conductor temperature, with which it is easy to accurately determine the allowable current level.

2-2 Overview of Sumitomo Electric's system

The system under development at Sumitomo Electric consists of multiple data collecting terminals directly installed on transmission lines, as illustrated in Fig. 2. These terminals measure temperature and current value of

Table 1. Comparison of sensed parameters

Monitored parameter		Conductor temperature	Tension	Conductor's angle of inclination
Installation location		Conductor surface	Tension tower	Suspension tower
Sensor		Surface thermometer	Conductor tension gage	Clinometer
Feature	Sensor structure	Relatively simple	Need to modify insulator	Relatively simple
	Power supply	Sensor generates power	Solar cell + Battery	Sensor generates power
	Measurement accuracy	Excellent	High	Low
	Determining permissible current	Easy to compare permissible current with conductor temperature	Need to convert tension to temperature	Need to convert angle of inclination to temperature

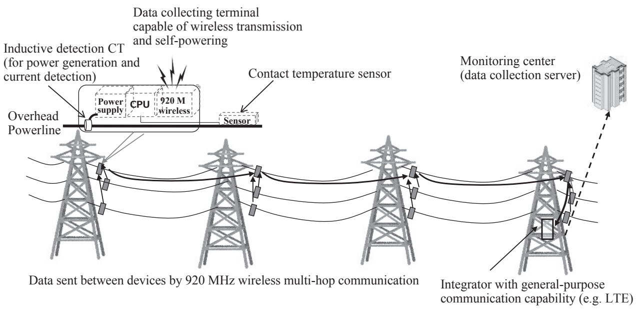


Fig. 2. Schematic diagram of system

transmission lines.

The data collecting terminal, which is directly installed on a high-voltage conductor, must be insulated, which makes it difficult to supply power to it from an external source. Therefore, the data collecting terminal was designed to generate necessary power by itself from the transmission line current.

The self-powering capability eliminates the need for regular maintenance as would be required with battery-powered terminals.

In addition, the data collecting terminal has the hopping function that relays information transmitted from a data collecting terminal of the proximity wirelessly. Using this function, temperature and the current values that the collecting terminals measured are transmitted to the concentrator using the radio of the 920 MHz zone while relaying it between collecting terminals and are finally transmitted from the concentrator to a data collection server using LTE lines.

Since the data are transmitted from the concentrator, this system can collect data along transmission lines even in mountainous areas outside the service areas of public networks, and the system uses the mobile line or another line to send data at once from the concentrator, even later we can build a network necessary for information transmission easily. In this way, it is possible to reduce public network costs even with the use of the mobile line.

Another possibility of the data transmission route along a transmission line using multi-hop communication is that the system could be used as a new communication infrastructure, incorporating information other than temperature and current value data from other sensors via the data collecting terminals.

Wireless multi-hop communication is generally configured as a mesh network, typically with 20 links or less due to complex routing. However, some long-range overhead transmission lines are several tens of kilometers in total length. With such power transmission lines, wireless mesh networks might fail to transmit data over the entire length. Our system is designed to enable communications using 50 links owing to a newly developed serial-hopping mode, considering the installation of terminals along a line, as shown in Fig. 3.

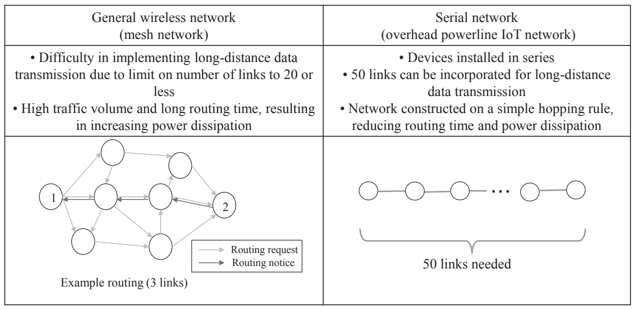


Fig. 3. Hopping mode comparison

Customized into a simple design, this hopping mode effectively simplifies the hopping table and reduces power dissipation.

3. Details of Newly Developed Equipment

This system consists of data collecting terminals installed on transmission lines and a concentrator that collects measurement data. The following sections explain the progress of development of these terminals.

3-1 Data collecting terminal

Figure 4 shows a block diagram of the data collecting terminal. The terminal consists of a current transformer

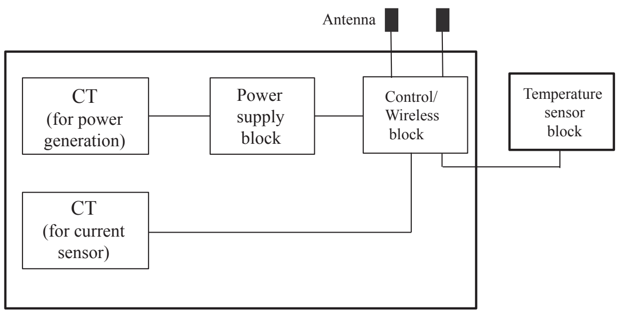


Fig. 4. Block diagram of data collecting terminal

(CT) for power generation, a power supply block, a CT for the current sensor, a temperature sensor block, and a control/wireless block. The CT for power generation generates an induced current from the magnetic field produced by the transmission line current. The power supply block generates direct current power from the alternating current power produced by the CT for power generation. The temperature sensor block measures the transmission line temperature. The control/wireless block processes the obtained temperature and current value data and sends the data to the concentrator by multi-hop communication.

Photo 1 shows the exterior of the data collecting terminal, Photo 2 shows the inside structure, and Table 2 lists the specifications. This terminal must be easy to install because installing it on a transmission line involves working on high places and the electric outage time should be short. The terminal has a cylindrical structure that can be split into two parts, as seen in Photos 1 and 2. Installation involves merely securing its conductor holding part onto a transmission line followed by tightening the screws on the sides of the cylinder.

This terminal must also be highly reliable and maintenance-free because once mounted on a transmission line it cannot be removed without shutting down the transmission line. This terminal requires no battery because it has a self-powering capability. It does not use machine relays or aluminum electrolysis capacitors, which are life-limited components, and thus achieves a long life design. Moreover, the terminal is robustly designed to prevent the entry of rainwater running along the conductor. More specifically, to create a fully closed structure, the inside of the terminal is filled with a polymer. Additionally, the cylindrical structure suppresses corona discharge, enabling it to be installed on a high-voltage conductor for stable long-life operation.

The temperature sensor is constructed to be directly installed on a conductor for improved measurement accuracy. The distance between the main assembly and the sensor and the position of the sensor are adjustable to allow for varying installation locations. While the temperature sensor component is separated from the main assembly in the prototype terminal, it is also possible to contain the temperature sensor in the main assembly.

The wireless block uses 920 MHz wireless technology. The hopping mode required for wireless transmission was developed in-house.

The data collecting terminal installed on a transmission line is subject to a rise in temperature due to increases in the conductor temperature in addition to the heat generated by itself. The temperature of an aluminum conductor steel reinforced (ACSR) line used for general applications may increase up to its maximum allowable temperature of 90°C. Accordingly, the terminal is designed to ensure operation under this high-temperature condition. Moreover, if a transmission line problem occurs, a short circuit current may occur until the line is shut down, although for a short length of time. Therefore, the terminal is protected against such short circuit current.

The firmware used to operate the terminal is designed to be able to update itself by downloading programs from the concentrator when a software bug is detected or a functional update becomes necessary. Two generations of the firmware are retained to ensure usability.

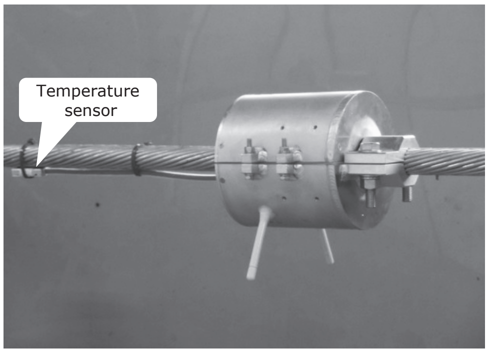


Photo 1. Exterior of data collecting terminal

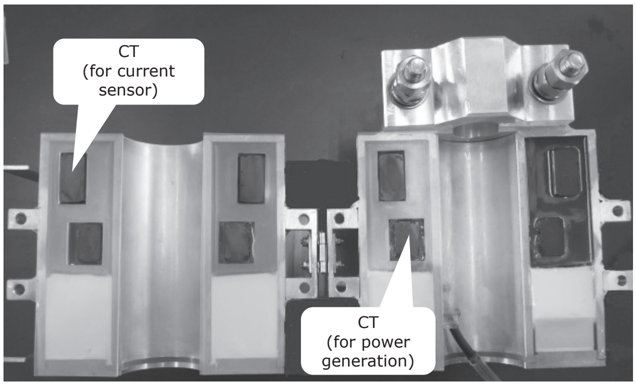


Photo 2. Inside structure of data collecting terminal

Table 2. Specifications of data collecting terminal

Parameter	Specification	Notes
Drive current	50-1,000 A	Powerline current for driving the device
Measured current	50-1,000 A	
Target current accuracy	±2%	
Temp. measurement range	-20 to +105°C	
Target temp. accuracy	±2°C	
RF920 wireless block	ARIB-STD-T108 compliant[1] Max. no. of links: 50 Frequency: 920 MHz band Output: 20 mW Propagation distance: 1 km or more (line-of-sight distance)	
Measurement interval	10 min	
Dimensions	Φ150 × L 146 (mm)	Excluding conductor holding part
Weight	Approx. 5 kg	
Design life	10 years or more	Limited-life componets not used

3-2 Concentrator

Figure 5 shows a block diagram of the concentrator. The concentrator is comprised of a 920 MHz wireless block that receives sensor data from data collecting terminals and an LTE router block that integrates the sensor data and transmits it to the monitoring center. To ensure data security, both the contracted LTE channel and the hosting service of the data collection server do not use the internet. As for installation locations, it is assumed that the concentrator will be installed on a tower or the roof of a building near the tower. A concentrator installed on a tower will be powered by the combination of a solar panel and a battery because of the difficulty in providing 100 V AC power or other external power supply. The power dissipation of the concentrator was optimized so as to reduce the capacities and weights of the solar panel and battery suitable for equipment installed on a tower. In doing this, Sumitomo Electric drew on its experience in developing and shipping various products for monitoring overhead transmission lines.

Photo 3 shows the exterior of the concentrator. Photos 4 and 5 depict the exteriors of the 920 MHz antenna housing and the LTE antenna used in the test. In addition, Table 3 lists specifications for the concentrator.

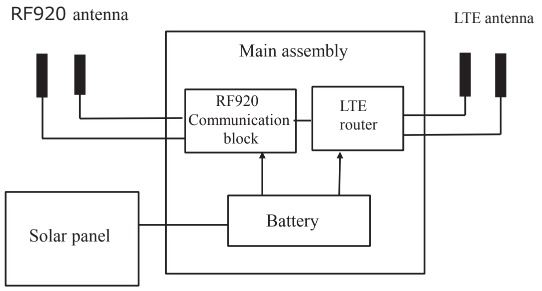


Fig. 5. Concentrator block diagram

Photo 3. Exterior of concentratot main assembly

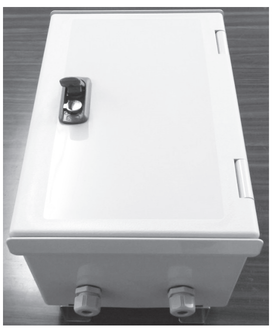


Photo 4. 920 MHz antenna

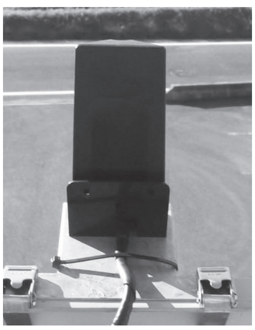


Photo 5. LTE antenna Housing

Table 3. concentrator specifications

Parameter	Specification	Notes
Power supply	Solar panel + Battery	
RF920 wireless block	ARIB-STD-T108 compliant[(1)]	
LTE wireless block	ARIB-STD-T63 compliant[(2)]	
Measurement interval	10 min	
Dimensions	H800 × W45 × D400 (mm)	Main assembly
Weight	Approx. 65 kg	

4. Evaluation Conditions

4-1 Operation test

We verified that the data collecting terminal operated stably with regard to the following basic capabilities when tested by installing the terminals on a live test transmission line at a testing site of Sumitomo Electric, as seen in Photo 6.

- The terminal produces power for operation (Self-powering capability).
- The terminal measures the physical quantities of transmission line temperature and current value (Sensing capability).
- The terminals relay the obtained physical quantities along the route from terminal 3 to terminal 2 to terminal 1 and to the concentrator (Data transmission capability).

Photo 6. Terminal operation test under live condition

4-2 Environmental tests on data collecting terminals

As mentioned earlier, the data collecting terminal must be extremely reliable because it is directly installed on a overhead transmission line. Using various test apparatuses, we conducted the environmental tests listed in Table 4 and verified that the data collecting terminal had no reliability issue.

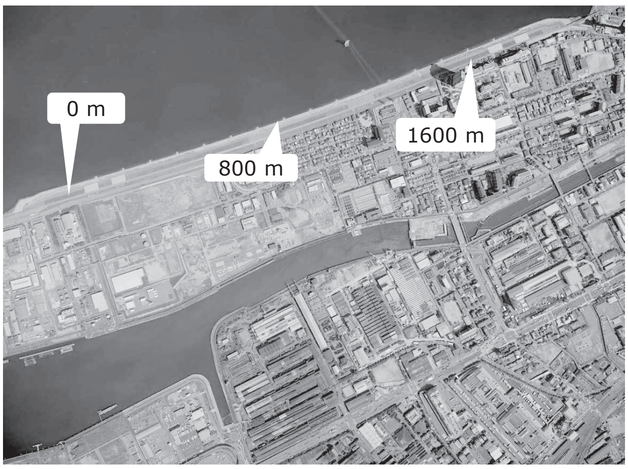
Table 4. Tests conducted on data collecting terminal

№	Test	Description
1	Waterproof	Operation checks by immersion at a depth of 50 cm
2	High-temperature operation	Operation checks after storage in thermostatic chamber at 105°C for 12 h
3	Low-temperature operation	Operation checks after storage in thermostatic chamber at −20°C for 12 h
4	Heat resistance	Operation checks after storage at conductor temperature of 125°C for 400 h
5		Operation checks after storage at conductor temperature of 150°C for 100 h
6	Heat cycle	Operation checks after 100 heat cycles between −20°C and 105°C
7	Vibration	After 10,000,000 vibration cycles at a conductor strain rate of ±100 ppm, check that the enclosure has no fracture or loose screw
8	Corona noise	Check for corona noise at Gmax of 10–16 kV/cm
9	High electric field	Strong magnetic field
11	Strong magnetic field	Operation checks after application of strong magnetic field at 3,000 A
12	Short-circuit current	Operation checks after passage of 63 kA through conductor for 1 s

4-3 Operation and performance evaluation of wireless block

The multi-hop routing used by this system was programmed to function for up to 50 links. Data collecting terminals were installed along a line. To reduce networking time substantially, each terminal was routed to send packets to terminals with larger identification (ID) numbers from downstream to upstream terminals (from smaller to larger ID-numbered terminals). Moreover, the use of our proprietary data structure enabled the terminal to stop sending or receiving unnecessary data and to reduce transmission time, thereby improving real-time performance and saving power.

For multi-hop relay testing, an experimental system was constructed on company premises to test the communication capability with 50 links.



Reference : Aerial photo of Geographical Survey Institute

Photo 7. Location of data transmission distance test

For data transmission distance testing, we perform it on a river bed to ensure no large obstructions along the line of sight. Antennas were placed at a height of 5 m. Test distances were up to 1,800 m at 200-m intervals. The system performed stable error-free communications up to 1,200 m. Data losses occurred infrequently between 1,400 and 1,800 m due to adverse effects of phasing and other factors. However, by providing a retransmission capability to the firmware, the system exhibited error-free operation for practical purposes and had no data transmission problems.

5. Future Prospects

According to the results of demonstration testing overseas, dynamic rating systems have been reported to increase transmission line capacity by 30% or more. While this report discussed a sensing method of installing sensors directly on a conductor, some papers report that the use of meteorological conditions (e.g. temperature and wind speed) measured in the area of the conductor to determine the allowable current, instead of the conventional fixed calculation constants, enhances transmission line capacity. The newly developed system of taking direct measurements of conductor temperature and current value will enable more efficient management of transmission lines based on monitored transmission line conditions than the conventional way of managing transmission lines without using adequate data on the allowable current carrying capacity. In some overseas countries, the use of dynamic rating as feedback information incorporated in operation control has been tested and proven. In Japan, to implement automated operation control, it is necessary to ascertain the true state of power transmission facilities based on a wealth of data and to establish a more reliable control scheme. The amount of electricity generated by wind power is expected to increase dramatically in the future as a renewable energy source. In Japan, a project has started to review the current carrying capacity of power transmission lines based on data on temperatures measured in overhead transmission line areas. The system discussed in this paper is expected to improve the accuracy of capacity forecasts and to lead to more efficient management.

Additionally, this system may be used for applications beyond dynamic rating, such as for communication infrastructure along overhead transmission lines. In some locations, overhead transmission lines are installed outside areas served by public networks, and could be used as a wireless transmission platform in areas where the low power wide area (LPWA) communication technology, which is recently attracting attention, is not available. The transmission of data from various sensors installed near transmission lines will add value to this system, such as data on mountain weather and landslides.

Data uploaded for cloud computing via the concentrator may be analyzed by artificial intelligence (AI) or machine learning. This may help improve maintenance efficiency and extend the service life of power transmission facilities by diagnosing service life.

It is planned to test and prove the operation of this system at a power company in fiscal 2018. We will commercialize this system after verifying its reliability by collecting long-term data.

6. Conclusion

Sumitomo Electric will further evaluate and verify the newly developed demonstration system and will develop a useful system for improving the efficiency of maintenance and management of overhead transmission line facilities.

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