Sensors Used for Controlled Switching System

Author: *Akihide Shiratsuki** and *Ryuichi Nishiura**

1. Introduction

To expand the scope of application of the controlled switching system, we developed a travel sensor for noncontact detection of electrode travel and a voltage/current sensor capable of completely nongrounded measurement as easy-to-use and low-cost sensors for the controlled switching system.

2. Travel Sensor

In the controlled switching system, parameters are corrected based on the actual value of operating time measured by the travel sensor to predict the next operating time, with the travel sensor as the key technology. In the conventional controlled switching system, the rotation sensor (encoder) is used to detect contact travel during the switching time. However, installing the system on existing equipment requires extensive modification of the synchronized driving system and it is difficult to apply the system. As the system will be applied to a wider range of applications, including existing equipment and many additional models, an easy-to-retrofit travel sensor based on a new system was requested.

As the method for detecting electrode travel, we propose a system in which the reflector is attached to the shaft connected to the electrodes and the position of the reflector moving with the shaft is detected optically, with no contact.

Figure 1 shows the principle of the proposed travel sensor. As the reflector to be attached to the shaft, a retroreflector that reflects light in the same direction as the incident direction of light is applied. The head of the travel sensor consists of a line image sensor that is a one-dimensional picture element, an imaging lens that forms an image of the light reflected from the reflector on the line image sensor, and a light-emitting diode (LED) as the light source. In addition, there is a coaxial optical system that uses a half mirror to ensure that the visual field of the line image sensor and the plane exposed to LED light are in the same plane. When the reflector moves with movement of the shaft, the position of the reflector image formed on the line image sensor also changes. Since the electrical signal output from the line image sensor becomes the brightness signal that peaks at the position of this formed image, the reflector motion, that is, the electrode motion, can be detected from the peak position of the picture element. Only the configuration of the sensor as previously discussed, with the reflector attached to the shaft and the sensor head installed so as to allow the reflector to enter the visual field of measurement, enables noncontact detection of electrode travel.

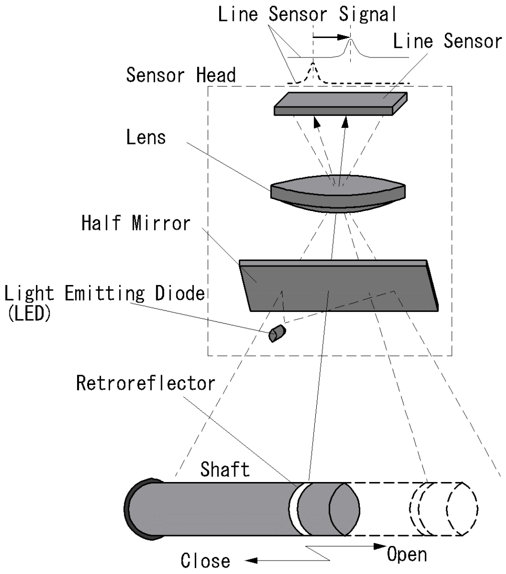

Fig. 1 Principle of travel sensor

The line image sensor used in the travel sensor has a resolution of 2,500 pixels or more, which can attain the target specification. The LED light source is configured to emit pulsed light (pulse width: 6.6 μs) at the blanking time of the line image sensor and ensure that no detection error is caused by image blur even during movement of the shaft.

With a manufactured prototype attached to an actual breaker, the changes in position of the shaft during breaking and making procedures were measured. At the same time, a conventional encoder was used for measurement. Figure 2 shows the results of measuring the travel sensor output and encoder output during 100 making tests.

As shown in Fig. 2, highly repeatable measurement results were obtained for 100 measurements. In the domain from 30 to 60 ms after starting measurement, a difference occurred between the encoder output value and travel sensor output value. While the encoder measures the rotational motion based on the movement of the shaft, the travel sensor directly meas-

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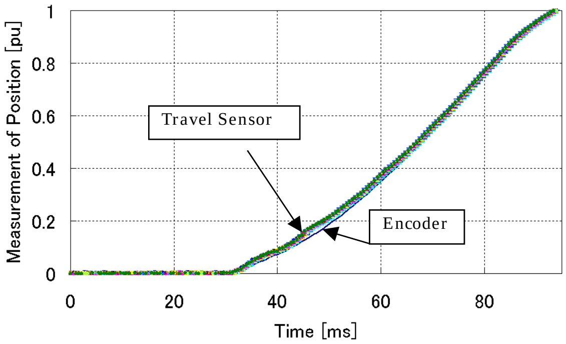

Fig. 2 Output of the travel sensor and encoder

ures the motion of the shaft. Therefore, the travel sensor is assumed to have detected wobbling due to play in the driving mechanism that cannot be detected by the encoder. In other words, the travel sensor faithfully detects the motion of the shaft.

At the position of 75 ms after starting measurement, the difference values between the travel sensor and encoder outputs were obtained to calculate their variations. The resulting value was a standard deviation (σ) of 0.14 mm. Considering that this value also includes encoder output variation, it means that high repeatability can be obtained, proving that the travel sensor has sufficient performance as an electrode travel sensor.

3. Voltage/Current Sensor

We developed a voltage/current sensor that measures voltage waveform on the load side and monitors current waveform in the controlled switching system for transformers and power lines. Since the controlled switching system standardizes and uses voltage waveforms as control parameters, a voltage sensor is regarded as functioning sufficiently if it can obtain the relative output signal.

The conventional device requires an isolator for ensuring isolation to ground, which is a main cause of the high cost. With the first aim of reducing cost, the sensor was designed to eliminate the need for the isolator and enable completely nongrounded measurement. This sensor roughly consists of a voltage measurement section, current measurement section, and radio data transmission section. Figure 3 shows an image of the sensor, and Table 2 lists the measurement specifications.

In the above voltage sensor, the current measurement section uses a conventional air-core coil current sensor. Details of the newly developed voltage measurement section and radio data transmission section are discussed below.

The method by which the voltage sensor is grounded to measure the overhead wire voltage to the ground requires an expensive member such as an isolator due to the problem of withstand voltage. Therefore, as shown in Fig. 4, a capacitor voltage dividing system employing a capacitor using air as the dielectric was designed.

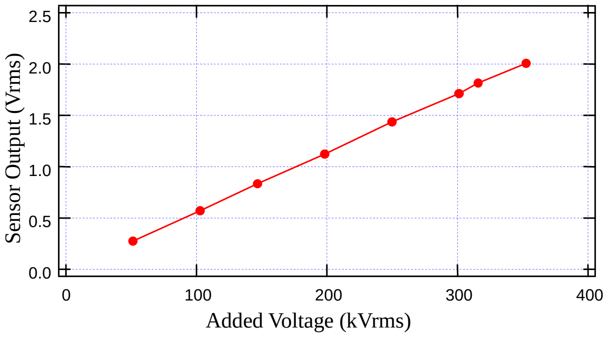

Fig. 4 Result of high voltage measurement

In this system, an electrode (intermediate electrode) paired off with the ground is provided to form the capacitor. With the voltage divided by this open-air capacitor and measurement capacitor, the potential at both ends of the measurement capacitor is the differential measured to measure the voltage. The ground of the sensor circuit is connected to the high-voltage overhead wire to place the sensor and high-voltage overhead wire at the same potential, which eliminates

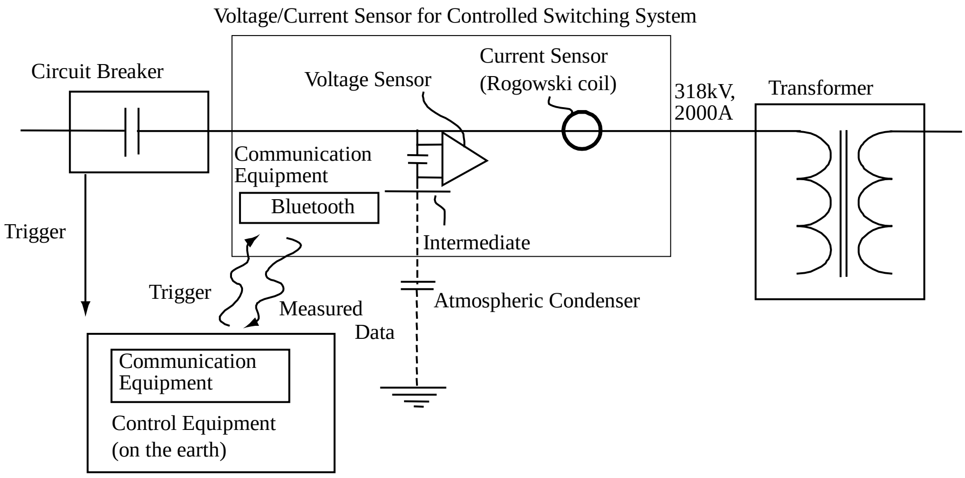

Fig. 3 Schematic diagram of voltage/current sensor

the need to take into account the withstand voltage.

In order to verify the principle, a prototype was manufactured and a high-voltage verification test was performed. As shown in Fig. 4, the verification test results confirmed that this sensor can measure voltage of up to 350 kVrms for high-voltage overhead wires with linearity of ±1.6%FS and proved that it is useful as a voltage sensor for the controlled switching system.

Since the purpose is to measure the voltage of high-voltage overhead wires (318 kVrms), the wire portion must be deleted due to the problem of withstand voltage. Thus wireless communication is employed for data transfer. If wireless communication is used for data transfer, there is a concern that electromagnetic noise such as corona discharge in the high-voltage overhead wire would adversely affect data transfer. Therefore, digital communication is indispensable, but real-time measurement is difficult since retrying data transfer causes delay due to the effect of electromagnetic noise. To solve this problem, we developed a digital wireless communication device that can use Bluetooth having a synchronous communication mode to ensure time synchronization between the control unit (ground) and the sensor.

Specifically, as shown in Fig. 5, in the Bluetooth synchronous communication mode, transmission and reception modes (slots) are alternately switched for communication, the timing of which is polled to establish synchronization. This device detects the slot switch timing and corrects the timing table update cycle to ensure that the timing table is updated at the same timing between the control unit and the sensor. This enables correction of the measurement time for processing on the control unit side.

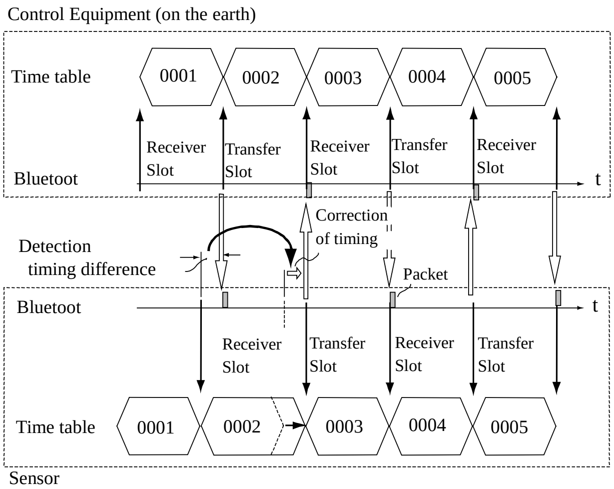

Fig. 5 Correction measurement time

In order to verify the principle of this time synchronization system, a prototype was manufactured and a verification test was performed. The verification test used a logic analyzer to measure the timing tables for two synchronous communication devices and the update time was monitored. In the verification test results, the values of the two timing tables matched within a time difference of 6 microseconds.

This verifies that the system can ensure time synchronization of 6 microseconds or less, and digital wireless data transmission based on this system maintains the time compatibility between the control unit and sensor.

These newly developed sensors are expected to expand the scope of application of the controlled switching system.