HIGH PRECISION DISTRIBUTION GRID MONITORING SYSTEM UTILIZING OPTICAL COMMUNICATION NETWORK

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ABSTRACT

In microgrid, the main power sources tend to be Distributed Energy Resources (DER), such as photovoltaic (PV) and wind power generations. PV and wind power generation output fluctuates continuously, and it makes power grid operation more complicated. In this situation, to ensure the stability of the grid, realization of advanced grid monitoring and control is required. To realize it, we developed the Distribution Automation System (DAS) utilizing optical communication network to monitor grid status highly precisely. In this paper, we introduce the developed system and the field trial results in actual power grid.

INTRODUCTION

In microgrid, DER, such as PV and wind power generation, is regarded as main power source. PV and wind power generation output fluctuates continuously depending on the weather. The power system status becomes complicated due to the fluctuation of the output and the direction of current power flow. This makes grid monitoring and control more complicated, shown in Fig.1. At present, monitoring and control of the voltage and the current within proper range and condition is one of the challenging issues to be addressed.

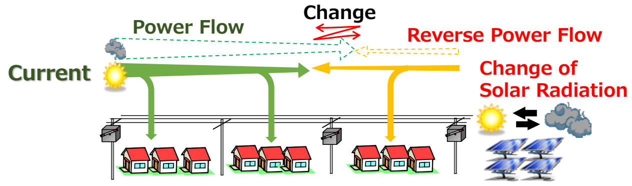

Fig.1 Current Fluctuation Problem by Photovoltaic

As a countermeasure to this issue, centralized monitoring and control method is studied as one of the candidate approaches; it monitors voltage and current with high-precision and controls distribution grid with equipment, such as Load Ratio Transformers (LRTs), Step Voltage Regulators (SVRs), and sectionalizers shown in Fig.2.
We had developed and introduced sensor-equipped sectionalizer, which has Current Transformer (CT) and Voltage Transformer (VT) to measure current in each phase and voltage between wires [1]. In this system, voltage and current data measured by sectionalizers in distribution grid is transmitted to the central master station server via the communication network. Based on the collected data, it is possible to grasp the distribution grid condition, and control the distribution equipment to maintain an appropriate electric power quality.
There is one study which propose one second interval data acquisition is required for centralized voltage control [2]. In order to realize the centralized monitor and control functions, high speed communication system, which is able to transmit huge amount of measured grid data and does not cause transmission delay, is required. In addition, considering to implement them in actual grid, system reliability and availability are also essential.

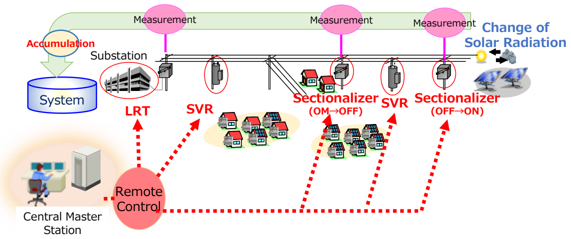

Fig.2 Centralized Monitoring and Control System

Here, we introduce DAS which is able to monitor high-precision voltage and current status with sensor-equipped sectionalizer utilizing optical communication network system. We also show the result through the field trial.

ADVANCED DAS UTILIZING OPTICAL COMMUNICATION

Requirement for optical transmission

We had started introducing DAS for improvement of monitoring and control of power grid in 1989, and has been utilizing it for our power system operation. The main purposes are to reduce the power outage duration and to improve the restoration work efficiency. In conventional DAS, coaxial or metallic twisted pair cable are used as communication media.
As described above, in the grid, where large amount of DER are connected, the status of grid could more sharply

fluctuate. To deal with this problem, in our newly-developed Advanced Distribution Automation System (ADAS) has the function of collecting the data measured by sensor-equipped sectionalizers with about one second interval, utilizing them, and monitoring the status of power grid system highly precisely.

For these functions of ADAS, the significantly faster communication system than that of conventional DAS is essential. Furthermore, we have to take "flexibility" into consideration in terms of design and operation of such communication system. In the case of relocation of utility poles, communication cable may be obstacle for such relocation work, which operators and field workers do not want to deal with. And the system "fault tolerance" are required, which enables stable communication in the case of faults on both/either of communication devices or distribution facilities (loss of power supply).

Development of Multi-hop Communication Method on Fiber Optic Network

To meet the conditions required for ADAS development, it was concluded that the fiber optic network was chosen as a communication media, based on the transmission rate, stability, reachable distance, communication delay (latency) and possibility of technological innovation. To ensure "flexibility" and "fault tolerance", various communication methods, that are applicable for fiber optic network, are considered; we reached the conclusion that multi-hop communication method on fiber optic network is to be the best for communication system of ADAS, figuring out the following ways to ensure "flexibility" and "fault tolerance" (shown in Table 1 and Table 2).

Ensuring Flexibility in Multi-hop Communication Method

The multi-hop method is a famous routing protocol based on Ad Hoc On-Demand Distance Vector (AODV) originally designed for wireless communication, which we utilize to wired fiber optic network. In this method, the communication between master station and slave station is conducted through repeating communication between slave stations automatically. This method enables distribution grid planners and operators to design and work simply; there is no need of any special knowledge or skill. For example, there is no need to consider logical connection routes, even in the case to add, remove or relocate slave stations.

Ensuring Fault Tolerance in Multi-hop Communication Method

Ring network is adopted as a logical topology; this enables the system to communicate with alternative route, even in the case of optical fiber disconnection on certain point. Moreover, mechanical optical switch is adopted as a measure against loss of power supply. Mechanical optical switch has the function to bypass optical signals mechanically. Therefore, even in the case that multiple slave stations get loss of power supply, the system is still able to communicate through other slave stations.

In addition, the ring structure is able to be easily created by dividing the core wire of the optical fiber cable in distribution system network of the tree brunch structure. Therefore, it is possible to utilize the existing optical communication line, and this feature contributes to construction at reasonable cost.

The configuration of the ADAS utilizing optical communication network is shown in Fig.3.

Table 1 Comparison of Communication Media

<table>
<tr><th colspan="2">Communication Media
(Communication Technology)</th><th>Transmission Rate</th></tr>
<tr><td colspan="2">Fiber Optic Network</td><td>○</td></tr>
<tr><td rowspan="2">Wireless</td><td>Mobile</td><td>△</td></tr>
<tr><td>Wireless Mesh</td><td>△</td></tr>
<tr><td colspan="2">Power Line Communication</td><td>△</td></tr>
<tr><td colspan="2">Coaxial / Twisted Pair
(Conventional System)</td><td>×</td></tr>
</table>

Table 2 Communication Methods for Fiber Optic

Communication Method	Flexibility	Fault Tolerance	Evaluation
Multi-hop Method	Simple design and operation (Connection between neighbouring slave stations)	Ensured by the application of ring network and mechanical optical switch	○
GE-PON Method	Complex design (e.g. Consideration of coupler branch design)	Communication is disabled in a wide area, in the case of repeater failure	△
Media Converter Method	Fiber core line is necessary for each slave station	The affected area is limited in faulty equipment	×

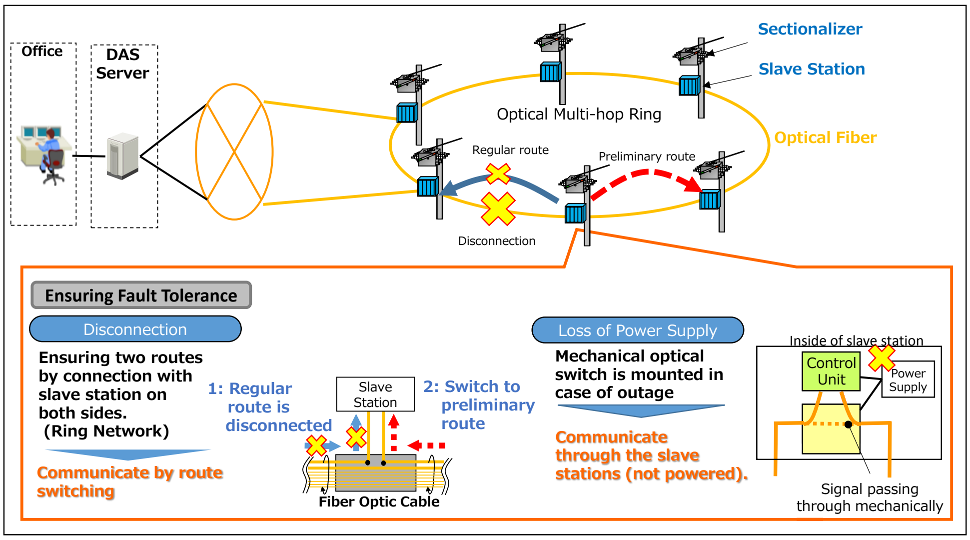

Fig. 3 Multi-hop Communication System Configuration and the Feature

ACTUAL FIELD TRIAL

To verify the function which measures one second interval data of grid status, we launched field trial; the number of sectionalizers (slave stations) are about 1,600. The field trial started in November 2017. We developed ADAS foreseeing the necessity and realization of centralized monitoring and control utilizing equipment, such as SVRs and sensor-equipped sectionalizers. However, at this stage, installed SVRs in this grid are autonomously operated; the tap changer, in each SVR, is autonomously operated based on the measured grid status.

Field Trial Result

We confirmed that all the one second interval data are collected in the DAS server successfully. And base on the analysis of collected data, we confirmed that the newly developed system is able to monitor significantly fluctuating grid status with high-precision.
An example of distribution feeder in the actual field trial is shown in Fig.4. Distribution feeder is connected with adjacent feeder by open sectionalizer. Several PVs of middle to large scale are connected on these feeders. 500kW PV is connected to Feeder 1, 100kW and 200kW PVs are connected to Feeder 2.

In Fig. 5, we show the highly precisely measured voltage data at sectionalizer S_3. This figure shows the voltage fluctuation on one sunny day. Around noon, steep voltage rise caused by load and PV output fluctuation is measured by sectionalizer S_3, and it is presumed that SVR tap changer was autonomously operated to supress the voltage rise.
In our conventional system, 10-minute interval grid status data is collected; the data collected with this granularity is indicated as blue-dots in Fig.5. As the result, we confirmed that the newly developed system is able to monitor significant voltage fluctuation that our conventional DAS could not see.
In Fig.6, we show the highly precisely measured current data at sectionalizer S_3. This figure shows the current fluctuation in the same day as Fig.5. It is presumed that the current value changes significantly due to load and PV output fluctuation. Same as with the result shown in Fig.5, we confirmed that the system is able to monitor steeply fluctuating current value that our conventional DAS could not see.

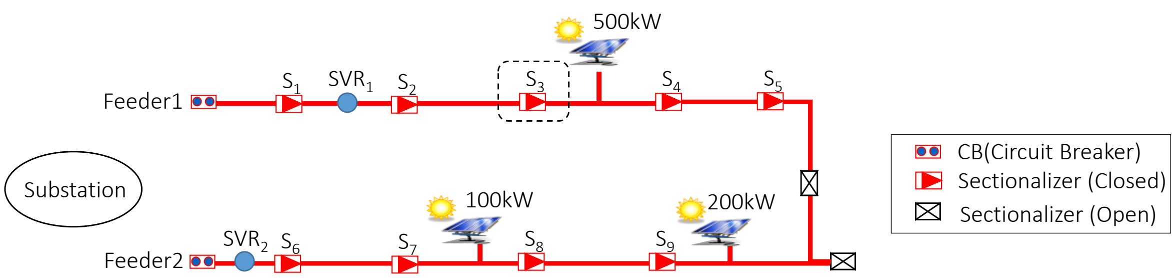

Fig.4 Example of Distribution Feeder in the Actual Field

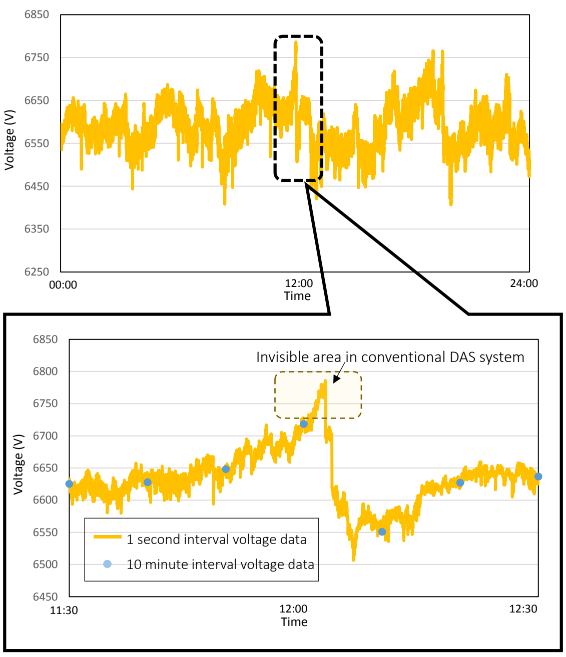

Fig. 5 Voltage Measurement Data

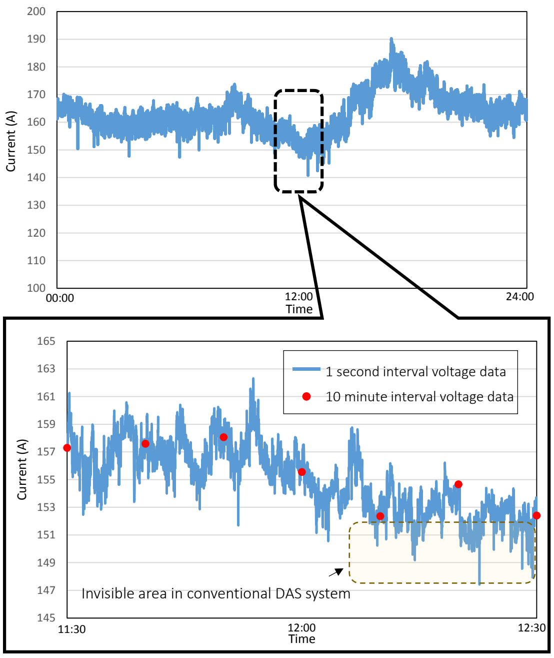

Fig. 6 Current Measurement Data

CONCLUSION

In microgrid, the state of the distribution system becomes complicated due to PV and wind power generations, and centralized monitor and control method is studied as one of the candidate approaches. In this paper, we have been developing ADAS utilizing optical communication network that is able to monitor grid status with high-precision, foreseeing the necessity and realization of centralized monitor and control system. To realize the function, the multi-hop communication method on fiber optic network is developed as one of the essential technologies for ADAS. In the process of development, we had taken the actual operation, "flexibility" and "fault tolerance", into consideration.

Through field trial, we confirmed that our newly developed system is able to monitor and collect one second interval data of voltage and current successfully. In addition, we confirmed that our new system is able to monitor the significant fluctuation of voltage and current due to the large amount of DER, which our conventional system could not see. This functionality is going to be essential for the realization of microgrid.

We continue to evaluate the developed communication system in actual field, and to utilize the system for the stability in a variety forms of power grids.

Furthermore, utilizing this developed function, we are also considering and studying for the realization of instantaneous fault section isolation [3] and specification of the fault point utilizing waveform [4].

It is planed that ADAS complies the international standard stipulated in IEC 61850.

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