DEVELOPMENT OF DIGITAL TWIN TECHNOLOGY FOR OPERATION AND CONTROL IN DISTRIBUTION SYSTEM

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ABSTRACT

In recent years, residential and fielding photovoltaic generation systems are rapidly and massively connected to the distribution system in Japan. In addition, electric vehicles are gradually widespread, and there is a possibility that they will be introduced rapidly in the future. Furthermore, aggregators and Virtual Power Plant (VPP) operators will appear in the future, there is a possibility of collectively controlling them. Due to this influence, reliable voltage management and power flow management are becoming difficult, and technical development is becoming necessary.

On the other hand, distribution system in Japan in recent years, line sensors are being installed in order to measure the voltage and power flow at each point distribution, and the introduction of a system that can monitor the state of the power distribution system in real time is progressing. We are also developing analysis tools that can simulate the state of the distribution system in detail. In addition, the progress of IoT technology is rapidly progressing, and methods of applying it to grid technology are proposed.

In this paper, we describe the state of development of technology to apply the concept of digital twin proposed in the IoT technology to the operation and control in the distribution system, and the future development.

INTRODUCTION

In recent years, residential and fielding photovoltaic generation systems are rapidly and massively connected to the distribution system in Japan. In addition, electric vehicles are gradually widespread, and there is a possibility that they will be introduced rapidly in the future. Furthermore, aggregators and Virtual Power Plant (VPP) operators will appear in the future, there is a possibility of collectively controlling them. Due to this influence, reliable voltage management and power flow management are becoming difficult, and technical development is becoming necessary.

On the other hand, distribution system in Japan in recent years, line sensors are being installed in order to measure the voltage and power flow at each point distribution, and the introduction of a system that can monitor the state of the power distribution system in real time is progressing. We are also developing analysis tools that can simulate the state of the distribution system in detail. In addition, the progress of IoT technology is rapidly progressing, and methods of applying it to grid technology are proposed.

ESTIMATION SYSTEM FROM REAL SYSTEM TO DIGITAL SYSTEM

The power flow that can be measured by the distribution line sensor is the power flow that passes through the distribution line, but in many analysis tools, it is necessary to input it as the load amount and power generation amount connected to the distribution line. Furthermore, since the measurable power flow is the difference between the load amount and the power generation amount, it is impossible to measure the actual load amount and power generation amount. Therefore, the authors have developed (1) technology to estimate the distribution of load (power generation) from the passing power flow, and (2) technology to separate the difference into the load amount and the power generation amount.

Technology to estimate the distribution of load (power generation) from the passing power flow

Figure 1 shows the relationship between the measured values of the distribution line sensor and the load calculated from the values. The measured value of the distribution line sensor is the voltage of the sensor section, the active power and the reactive power flowing through the sensor.

The calculated load is the active load and the reactive load distributed to the three load points between the two sensors. Actually, the load cannot be calculated by only the information on the distribution line sensor and the line impedance of the distribution line as shown above. This is because if the above relationship is expressed in an equation and solved, it becomes an indefinite solution. In this paper, we restrict the load distribution and solve the above equation.

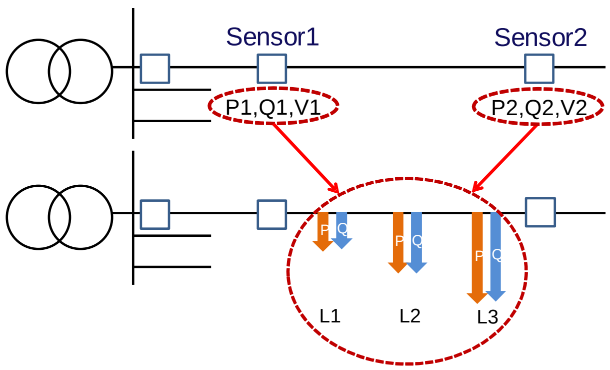

Fig.1 Load distribution estimation method

Technology to separate the difference into the load amount and the power generation amount

Fig.3 shows the relationship between mixed load and output of the photovoltaic power generation and separated into the load and the output of the photovoltaic power generation. In this separation method, the characteristic that the power factor of the load and the power factor of the output of the photovoltaic power generation are substantially constant is utilized. These loads and outputs of the photovoltaic power generation are drawn on a two-dimensional plane of active power and reactive power, and they are separated by using the relation of vectors (fig.2 and reference [2]).

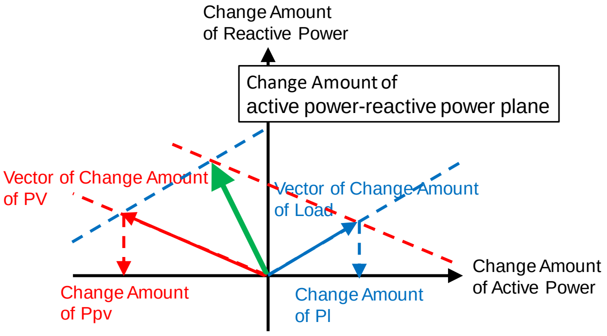

Fig.2 Concept of vector decomposition to estimate

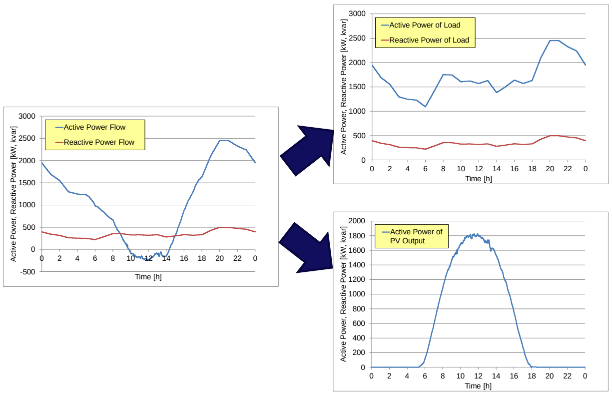

Fig.3 Method for separating power generation and load

ANALYTICAL TECHNIQUES AND TOOLS ON DIGITAL SYSTEMS

The authors have been promoting the development of the comprehensive analysis tool for distribution system and distributed generation (called CALDG) and data converting tools for distribution equipment, distribution line sensors and smart meters so far, we can simulate the phenomenon of the real system in detail on the digital system.

Tool to convert distribution equipment data of distribution operators to analysis system

Tool to convert distribution equipment data

As shown in Fig. 4, this tool converts the structure of the distribution line, the impedance of the distribution line, the connection position and the contract capacity of the customer, the interconnection position of the distributed power generation and the contract capacity managed by the power distribution operator. Then, it automatically fills in the developed analysis tool. In addition, these data can be displayed not only on the system diagram but also on the map. By using this tool, the analyser can perform the analysis efficiently (reference [3]).

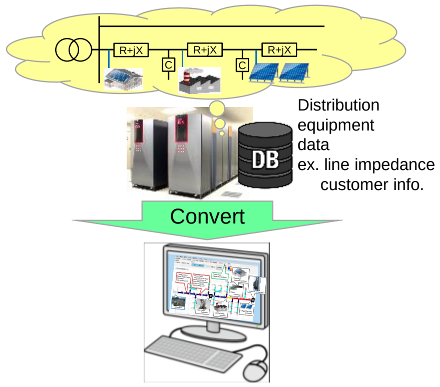

Fig.4 Converting distribution equipment data

Tool to convert distribution line sensors data

As shown in Fig. 5, this tool converts the measurement data of the distribution line sensors, which is managed by the power distribution operator, and automatically enters it into the developed analysis tool. Measurement items of the distribution line sensor data and measurement intervals are different for each power distribution operator, and it takes a lot of work to utilize these data for analysis. The tool includes a standard database proposed by the CRIEPI, and by standardizing the distribution line sensor data format of the power distribution operator in Japan, it becomes possible to utilize it in all analysis programs developed by CRIEPI.

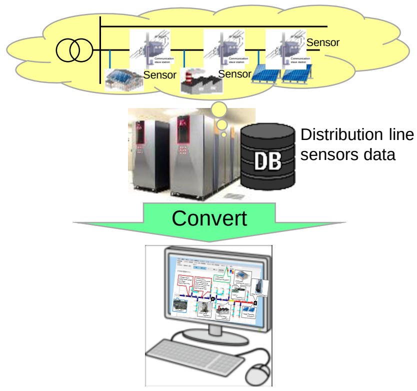

Fig.5 Converting distribution line sensors data

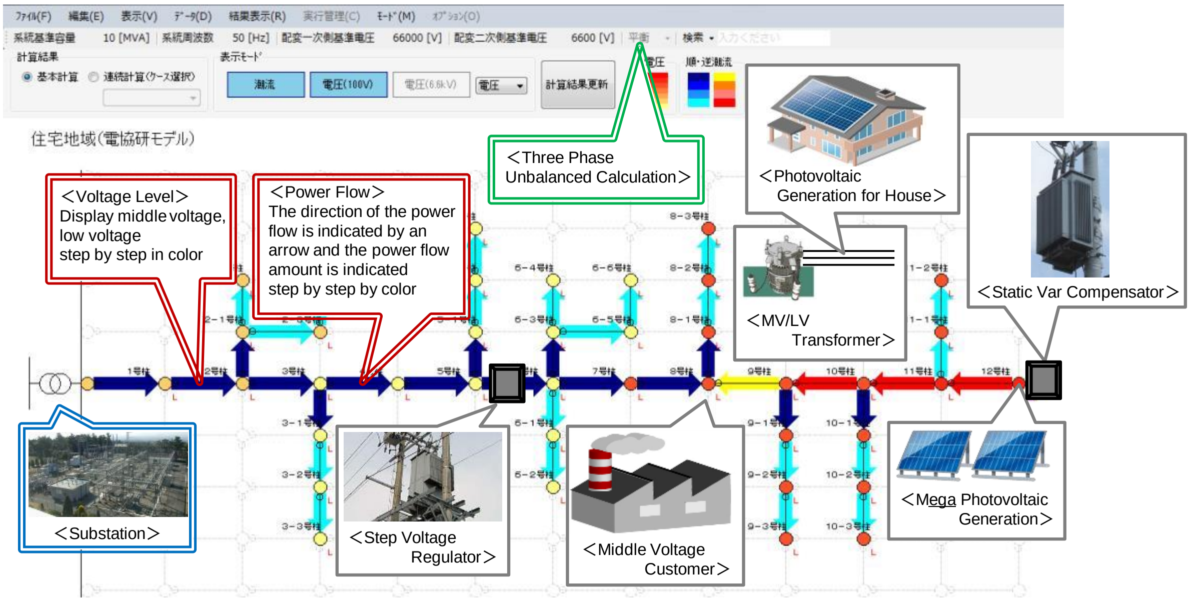

Fig.7 Comprehensive analysis tool for distribution system and distributed generation

Tool to convert smart meters data

As shown in Fig. 6, this tool converts the measurement data of the smart meters, which is managed by the power distribution operator, and automatically enters it into the developed analysis tool. Measurement items of the smart meters data are different for each power distribution operator, and it takes a lot of work to utilize these data for analysis. The tool includes a standard database proposed by the CRIEPI, and by standardizing the distribution smart meters data format of the power distribution operator in Japan, it becomes possible to utilize it in all analysis programs developed by CRIEPI.

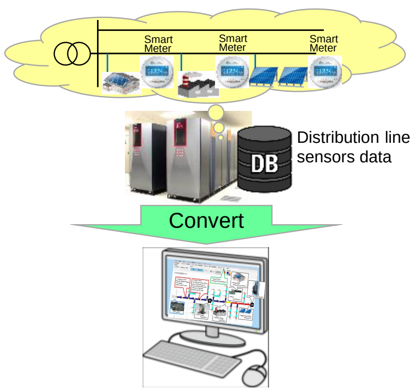

Fig.6 Converting smart meters data

Comprehensive analysis tool for distribution system and distributed generation (CALDG)

CALDG can simulate in detail the change of power generation output and load, the distribution operation equipment, and the control of customer equipment using by continuously connecting the power flow calculation. Recently, we have also added functions of harmonic calculation, short-circuit capacity calculation and fault calculation, and developed so that all phenomena in the distribution system can be simulated (fig.7 and reference [1]).

Voltage / power flow analysis function

Features of this tool are as follows.

(1) Control of distribution lines, change in demand of consumers and power factor control, output change and control of distributed power supply, etc. can be simulated.

(2) The analysis time interval can be set to 1 second at the minimum.

(3) Not only the equilibrium state but also the unbalanced state can be analysed.

(4) Analysis result can be displayed on CSV file, system diagram, map.

Harmonic analysis function

Features of this tool are as follows.

(1) From the configuration and impedance of the distribution line, the resonance frequency seen from a certain place can be obtained.

(2) If the harmonic source can be set, the voltage distortion at each point of the distribution line can be obtained.

Distribution lines fault analysis function

Features of this tool are as follows.

(1) It is possible to obtain the short circuit capacity at each point of the distribution line.

(2) The sensitivity of the protection relay of the substation against the ground fault accident can be obtained.

EXAMPLE OF ESTIMATION RESULTS TO DIGITAL SYSTEM

The load distribution was estimated from the distribution line sensor information using the distribution of load (power generation) from the passing power flow. In this technology, the load distribution is decided so that the values of the voltage, the passing through active power, and the passing through reactive power of each sensor are matched with the measured values. As shown in Fig. 8 to 10, the values of the distribution sensor are sufficiently coincident. From this, it can be confirmed that this technology is effective.

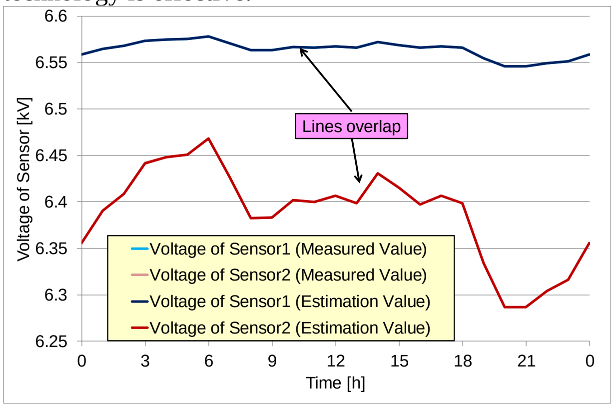

Fig.8 Voltage of Sensor

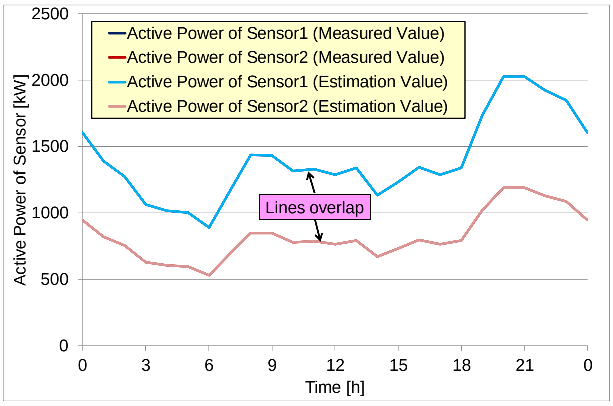

Fig.9 Active power of Sensor

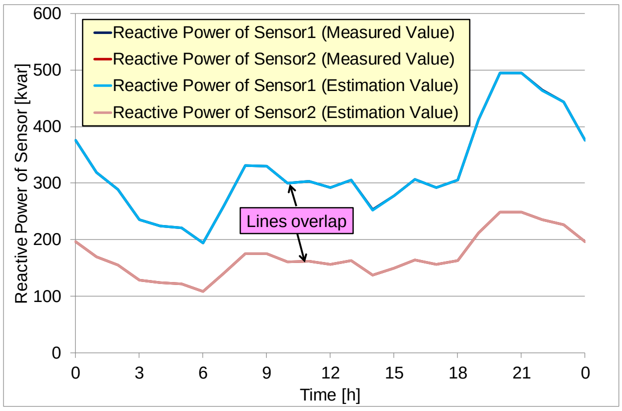

Fig.10 Reactive power of Sensor

As shown in Figs. 11 to 12, the actually measured load distribution and the estimated load distribution sufficiently coincide over 24 hours. This also confirms that this technology is effective.

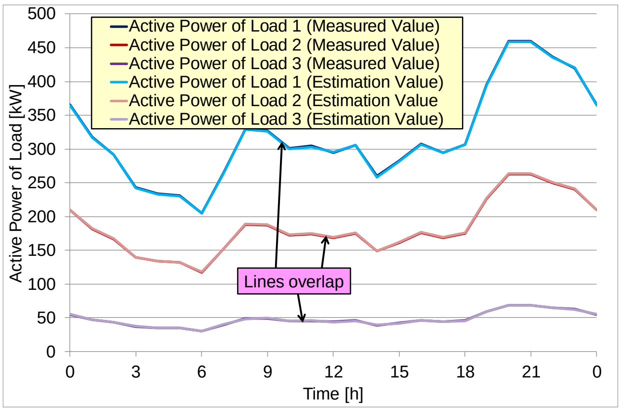

Fig.11 Active power of load distribution

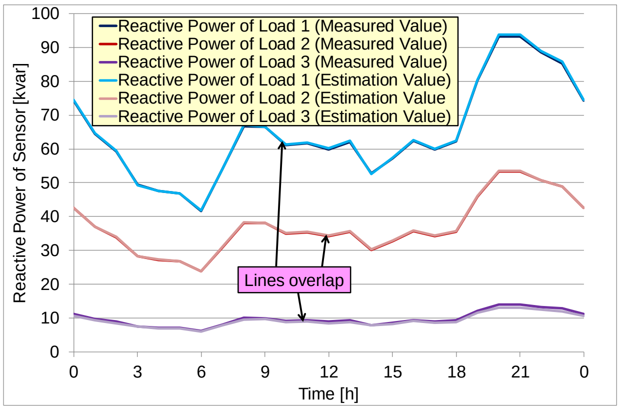

Fig.12 Reactive power of load distribution

EXAMPLE OF SIMULATION RESULTS BY USING PROPOSED TECHNOLOGY

Voltage and tidal current analysis were conducted on the case where photovoltaic power generation was connected to the end of the distribution line using the techniques and tools described so far. Fig. 14 shows the results on clear days, and Fig. 15 shows the results on the output fluctuation date. This result sufficiently simulates the situation of the actual distribution line, and it became clear that the digital twin technology can be utilized for the operation of the distribution line by using this result.

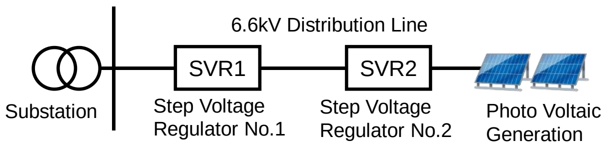

Fig.13 Distribution Line for Simulation Model

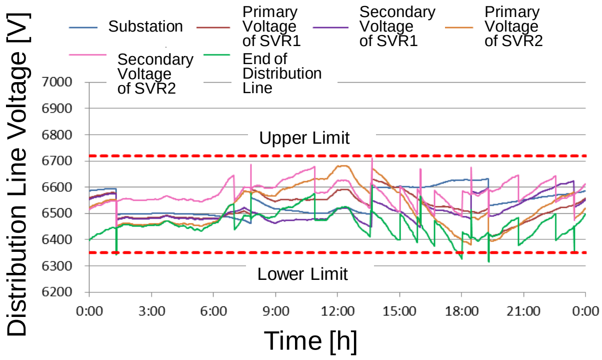

Fig.14 Simulation Results at Sunny Day

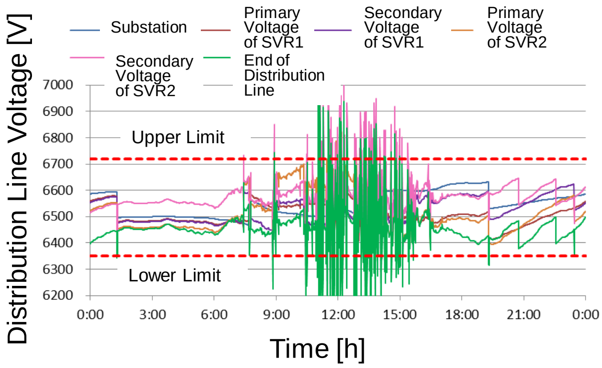

Fig.15 Simulation Results at Solar Radiation Fluctuating Day

CONCLUSION

As described above, we are developing technology to utilize digital twin technology for operation of distribution lines. Today, we are starting work to introduce this technology and tools into the actual system of electric power distributor, and after two to three years, three power distribution companies (only 10 electric distribution companies are in Japan) It is planned to complete introduction to the system.

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