DEMONSTRATION STUDY ON CENTRALIZED VOLTAGE CONTROL SYSTEM FOR DISTRIBUTION LINE WITH SUDDEN VOLTAGE FLUCTUATIONS

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ABSTRACT

The volume of distributed generation (DG) including renewable sources is growing. To keep the power quality of the distribution system with large volume of DG, a research project of "Demonstrative Project on Power Network Technology" regarding the new electric power system is carried out under the research contract with the NEDO. In the project, control devices such as static var compensator (SVC) and centralized control system to keep the voltage of the distribution line properly were developed. In this paper, the centralized control system is improved by the autonomous voltage control of SVC. The demonstration tests with sudden fluctuations of photovoltaics are carried out and effectiveness of the centralized control method is studied experimentally.

INTRODUCTION

In the recent distribution system, the volume of distributed generation (DG) including renewable sources is growing. If the penetration capacity of the DG is increased, the reverse power flow from the DG may have influence on power quality, especially on the voltage of the distribution system.

To cope with such problems, a research project "Demonstrative Project on Power Network Technology" regarding the new electric power system is carried out under the research contract with the New Energy and Industrial Technology Development Organization (NEDO) in Japan. The purpose of the project is to develop and to demonstrate the control devices and the control methods to keep the voltage of distribution line properly in case the large volume of DG is installed, and the research items are "Development of the Distribution System Control Device and Measure for Conventional Distribution System" and "Development and Demonstration of Loop Balance Controller for Future Loop Shaped Distribution System" [1].

As a part of the research project, a centralized control system to keep the distribution line voltage properly was designed and developed in the demonstration test facility at Akagi testing center of Central Research Institute of Electric Power Industry (CRIEPI). The control devices such as step voltage regulator (SVR) and static var compensator (SVC), which can be operated by either autonomous or remote control mode, were developed and installed in the test facility. The demonstration tests of the centralized control system were carried out, and the distribution line voltage was controlled properly by the centralized control system with SVC when the output power of the DG changes gradually [2].

In this paper, a centralized control system is improved by use of voltage reference and fast algorithm to obtain optimal control variables. Then demonstration tests to keep the voltage of the distribution line with sudden voltage fluctuations are carried out. The effectiveness of the centralized control system by use of the inverter type generators simulating sudden fluctuation of the photovoltaic system is studied experimentally.

CENTRALIZED CONTROL SYSTEM

A centralized control system is designed and developed as described below. It monitors the distribution line and calculates control variables of the control devices. Then, the calculated variables are sent to the control devices.

Concept of Centralized Control

The centralized control method is the remote control method by use of the communication network, the central system, sensors and control devices. As shown in Fig.1, the central system gathers data from sensors at the distribution line, and calculates control variables of each control devices, then send the control variables to the each control devices.

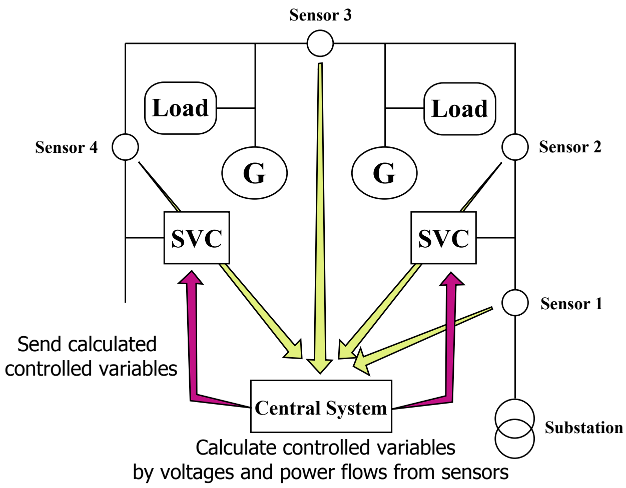

Fig.1 Concept of Centralized Control

Procedure of Centralized Control

The procedure of the centralized control method is shown in Fig.2. To calculate the optimal control variables, the central system monitors the voltage and the power flow by sensors at the distribution line. Then the central system performs the power flow calculation without control devices, and tries to find optimal control variables if the

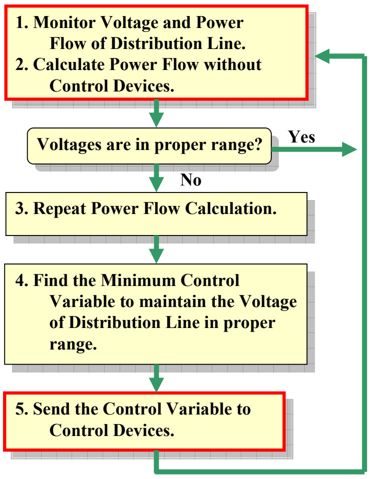

Fig.2 Procedure of Centralized Control

voltages are not in the proper range. The central system performs the power flow calculation repeatedly and picks up the optimal parameters of the control devices.

Calculation for Optimal Control Variable

In the centralized control method, the optimal control parameter of the SVC is calculated as the output reactive power, and the reference value of the SVC is the reactive power or the voltage. In this paper, the former one is called Q-reference and the other is V-reference. When the SVC is controlled by V-reference mode, the SVC is controlled as an automatic voltage regulator. To find the optimal control parameter faster, "Tabu Search" algorithm is adopted.

DEMONSTRATION TESTS

The demonstration tests of the centralized control system were carried out at Akagi testing center of Central Research Institute of Electric Power Industry (CRIEPI), and the distribution line voltage was controlled properly by the centralized control system with SVCs when the output power of the DG changes gradually [2].

In this paper, additional tests with rapid change of the DGs were carried out by use of the inverter type DGs simulating sudden fluctuation of photovoltaic generations.

Test Distribution System

Test distribution system is shown in Fig.3. The test distribution system consists of a substation, 6.6 kV distribution line, DGs, loads and SVCs. The actual length of the distribution line is about 2 km, and the equivalent line length is about 5 km by use of the resistors and reactors. The DGs and the loads are installed at three sites in the test distribution system. The DGs are the 100kW inverter type ones which simulate photovoltaic (PV) generation. The loads consist of the resistance and reactor. The maximum resistive load of them is 200kW and the maximum inductive load of them is 100kVar. Two SVCs

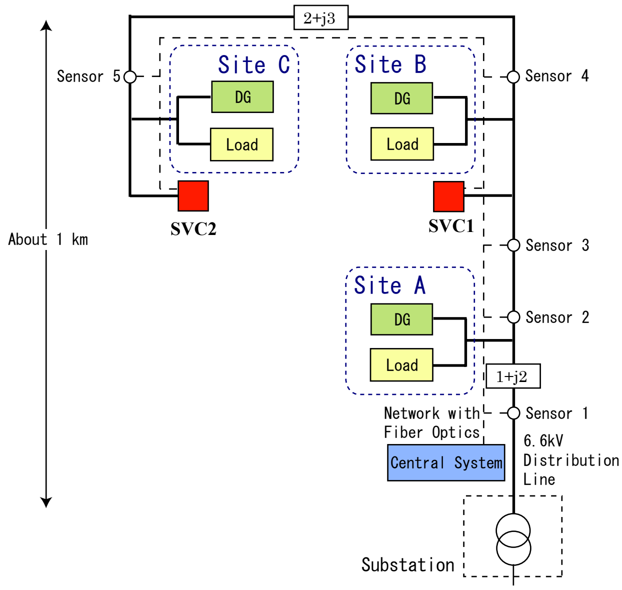

Fig.3 Test Distribution System

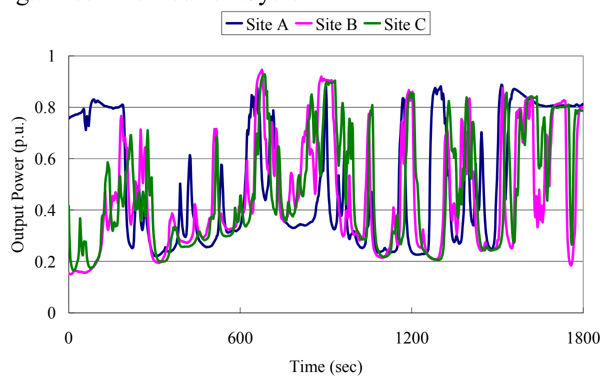

Fig.4 Output Pattern of DGs (Sudden Change of PV)

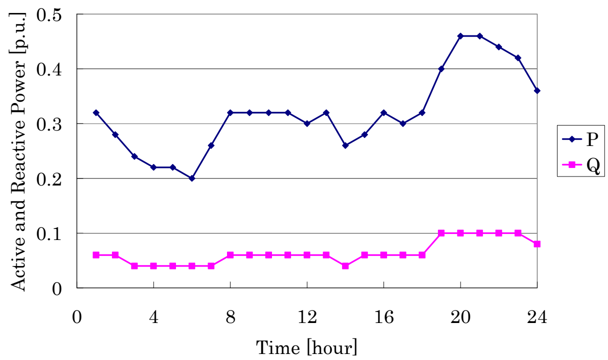

Fig.5 Load Curve

are installed at the middle and the end of the distribution line, and they are called SVC1 and SVC2, respectively.

Test Conditions

The DGs are operated by the output pattern shown in Fig.4. The output pattern is made by the solar radiation measured at the test site and the DGs simulate sudden change of PV generation in occasionally cloudy weather. Fig.5 shows the load curve, which simulates the load of the intermediate period. In this test, the amount of loads are set constant by the load at fourteen. The SVCs are controlled by the central system. The upper limit of the line voltage is 6725V (107V in low-voltage) and the control target voltage is 6694V (106.5V in low-voltage) considering the margin.

Test Result without SVC

Test result without SVC is shown in Fig.6. This figure shows the line voltage at middle and end of the distribution line during the test. When the output power of the DGs changes, the line voltage changes also, and the line voltage exceeds the upper limit sometimes.

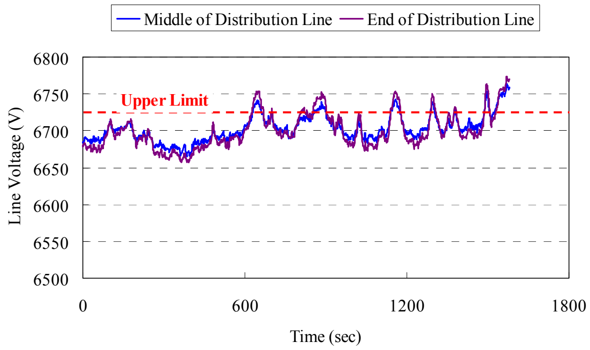

Fig.6 Line Voltage of Distribution Line (without SVC)

Test Result with a SVC

Then, the SVC2 is controlled by the centralized control method. Fig.7 and Fig.8 show the test results when the SVC2 is controlled by the Q-reference mode. In this case, the SVC controls the line voltage almost under the upper limit, but the voltage fluctuation remains and the line voltage reaches the upper limit a few times. Fig.9 and Fig.10 show the test results when the SVC2 is controlled by the V-reference mode. In this case, the line voltage is controlled under the upper limit and the voltage fluctuation is smaller than the Q-reference mode. To evaluate the test results statistically, the voltage data is ordered in descending order of magnitude. The duration curves of the line voltage are shown in Fig.11 and Fig.12. And the statistical data of the line voltage are shown in Tab.1 and Tab.2. It is confirmed that the voltage is controlled more stable by the V-reference mode than the Q-reference mode.

Test Result with two SVCs

To confirm the applicability of the V-reference control, the demonstration test with two SVCs were carried out. Test results are shown in Fig.13 and Fig.14. The line voltages are controlled under the upper limit and the hunting behaviour between the SVCs does not occur.

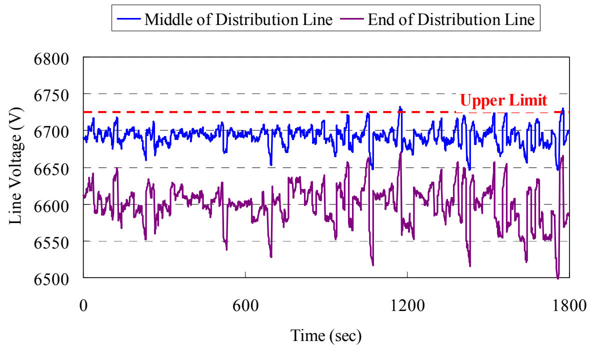

Fig.7 Line Voltage of Distribution Line with SVC2 (Q-reference)

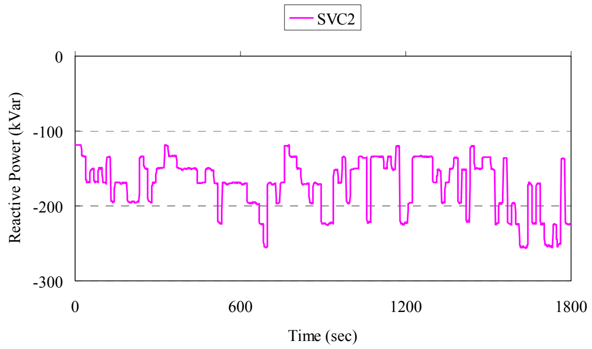

Fig.8 Reactive Power of SVC2 (Q-reference)

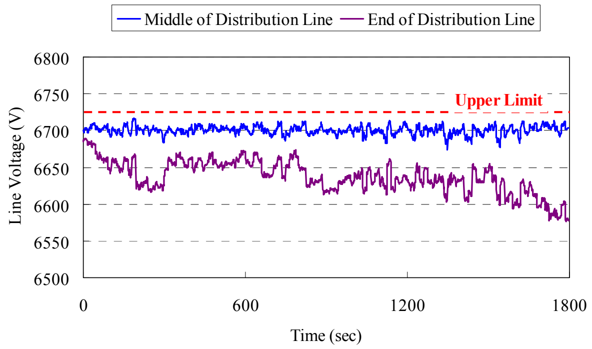

Fig.9 Line Voltage of Distribution Line with SVC2 (V-reference)

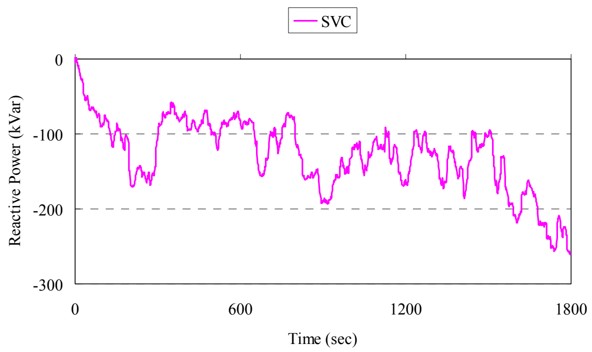

Fig.10 Reactive Power of SVC2 (V-reference)

Tab.1 Statistical Data of Line Voltage (Q-reference)

Voltage at Middle of Distribution Line				
Average	6692 V	Max	6732 V	
SD	13.1 V	Min	6646 V	
Voltage at End of Distribution Line				
Average	6600 V	Max	6670 V	
SD	27.2 V	Min	6498 V	

SD : Standard Deviation

Tab.2 Statistical Data of Line Voltage (V-reference)

Voltage at Middle of Distribution Line				
Average	6701 V	Max	6717 V	
SD	6.0 V	Min	6674 V	
Voltage at End of Distribution Line				
Average	6637 V	Max	6689 V	
SD	21.9 V	Min	6576 V	

SD : Standard Deviation

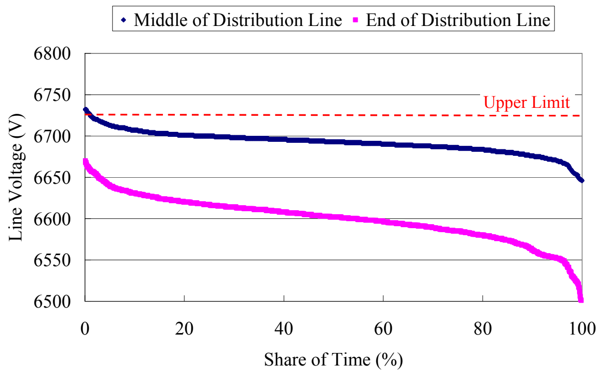

Fig.11 Duration Curve of Line Voltage (Q-reference)

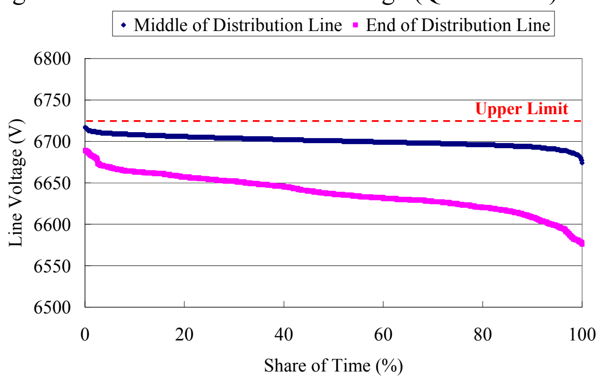

Fig.12 Duration Curve of Line Voltage (V-reference)

CONCLUSIONS

A centralized control system to keep the line voltage properly was designed and developed. Demonstration tests to keep the voltage of the distribution line with the SVC were carried out when the output power of photovoltaic generations change rapidly. The results show that the line voltage is controlled more stable by the V-reference mode than the Q-reference mode. When two SVCs are controlled by the V-reference mode centralized control, the line voltage is controlled properly, also. Then,

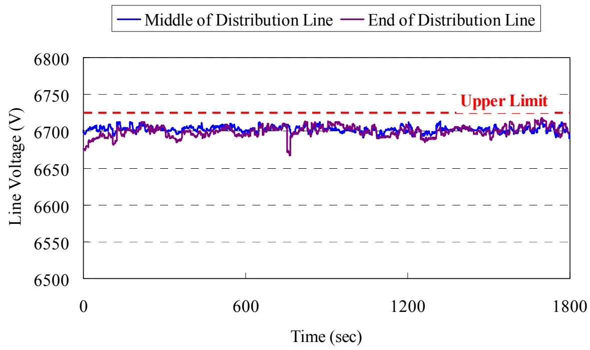

Fig.13 Line Voltage of Distribution Line (V-reference)

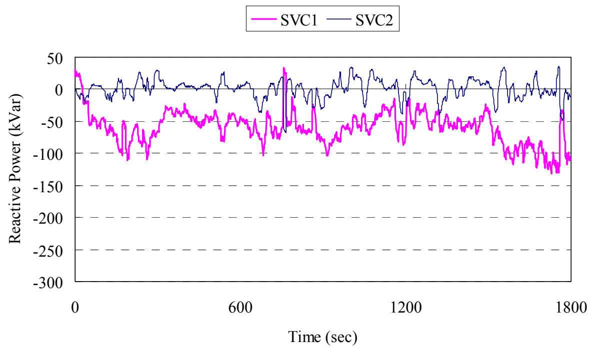

Fig.14 Reactive Power of SVC (V-reference)

it was shown that the centralized control is effective even if the output of DG such as photovoltaic generation changes rapidly.

Acknowledgments

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