DEVELOPMENT OF AUTONOMOUS DEMAND AREA POWER SYSTEM
-OPERATION AND CONTROL FOR REGULATION OF SYSTEM VOLTAGE-

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ABSTRACT
In 6.6kV power distribution system of Japan, the introduction of many distributed power generations (DGs) is expected. Under such circumstances, power flow congestion and voltage fluctuation on distribution lines caused by varied output of the DGs will occur. This will result in a failure to maintain power quality and supply reliability by conventional power system management.

In this paper, we have proposed a new power supply system referred to as the Autonomous Demand Area Power System (ADAPS). ADAPS may be in the loop formation, in addition to the conventional tree branch form. We try to establish network technology and operation management technology of ADAPS, and identify its effectiveness.

Using real scale experimental equipments, we performed reducing the voltage fluctuation caused by changing load and output of DGs, and regulating the system voltage by collecting system information via Supply and Demand Interfaces and controlling Loop Power Flow Controllers. Therefore, we checked that the operation method (by Operation Control System) of ADAPS was effective in the viewpoint of voltage regulation.

Moreover, we studied on suitable voltage regulation method (control voltage rise of DG, SVC control and LPC control) according to interconnection rate of DG by computer simulation about regulating system voltage in residential and commercial area models.

PURPOSES
In 6.6kV power distribution system of Japan, centered in urban areas with high power demand densities, the introduction of distributed power generations (DGs) including fuel cell and photovoltaic power generation are expected. Under such circumstances where many DGs are incorporated in the existing power system, power flow congestion and voltage fluctuation on distribution lines will occur, caused by varied output of the DGs. This will make the control of the whole power distribution system operation complicated, and result in a failure to maintain power quality and supply reliability by conventional power system management.

As a strong countermeasure of the issues, we have proposed a unique, new power supply system referred to as the Autonomous Demand Area Power System (ADAPS). ADAPS leads free access of the DGs to the grid and makes full use of the characteristics of the DGs, which feature the effective use of electric power and thermal energy at the demand side. To facilitate this proposed scheme, we try to establish network technology and operation management technology of ADAPS, and identify its effectiveness. Moreover, we study on suitable voltage regulation methods according to interconnection rate of DG in some areas.

BASIC CONCEPT OF ADAPS

Concept of ADAPS
Fig.1 shows expected future utility power system including ADAPSs. ADAPS is defined as the segment that includes the distribution system (=6.6kV) and the secondary system (=66kV) of power supply side in Japan.

Configuration of ADAPS
Fig. 2 shows an example of ADAPS configuration, and communication network structure. ADAPS may be in the loop formation, in addition to the conventional tree branch form. Loop Power Flow Controllers (LPC) for controlling power flow and voltage between loops will be needed. Operation Control System (OCS) and Supply and Demand Interfaces (S&D IF) per several customers will be installed for information exchange between supply and demand sides. OCS (central unit) aims for the power flow control of whole of ADAPS. The communication network is consists of optical fibers.
Fig2. Configuration of ADAPS

ADAPS OPERATION TEST BY USING REAL SCALE EQUIPMENT

Configuration of test power system

Fig.3 shows 6.6kV test power distribution system consist of some feeders and three LPCs. The main feeder of the system consists of three sections divided by sensors (No.2,3), and each section is connected by LPC with another feeder. The second section is interconnected with load-A and generation-A as a high voltage customer, the third section is interconnected with load-B and generation-B as a high voltage customer.

The communication network consists of optical fibers, media converters and hubs, and connects OCS with other components such as LPCs and S&D IFs. As ADAPS components except LPC, OCS is set in the control room of a substation, and S&D IFs is set in the load and generator rooms, both components consist of personal computers.

Configuration of LPC

LPC consists of two ac/dc converters linked to direct current (=Back To Back method), and enables the simultaneous control of power flow and terminal voltage at both power line sides. The two power lines can be connected together by the LPC even though voltages and phases between two lines are quite different. As the results, loop or mesh configuration can be composed in demand area. Additionally, because fault current of loop network can be isolated by LPCs, reliability of protection and safety of the network will be able to be maintained.

The composition, the rating and the appearance of LPC using this test are shown in Fig.4, Table1 and Fig.5.

![Fig.4 Composition of LPC](image)

<table>
<thead>
<tr>
<th>Table1 Rating of LPC and Transformers</th>
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<tbody>
<tr>
<td><strong>Main Circuit</strong></td>
</tr>
<tr>
<td>Rated Capacity</td>
</tr>
<tr>
<td>Rated Current</td>
</tr>
<tr>
<td>Switching Device</td>
</tr>
<tr>
<td>Carrier Frequency</td>
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</table>

*Rated Capacity (100kVA) is converted to 750kVA by the system capacity

![Fig.5 Appearance of LPC](image)

<table>
<thead>
<tr>
<th>Table2 Rating of a Synchronous Generator</th>
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<tbody>
<tr>
<td>Rated Capacity</td>
</tr>
<tr>
<td>Number of Poles</td>
</tr>
<tr>
<td>Rated Speed</td>
</tr>
</tbody>
</table>

*Rated Capacity (187.5kVA) is converted to 1406kVA by the system capacity

Configuration of load and DG

The loads are consists of resistances, reactors, capacitors and motor load. However, resistance loads are used in this case. The DG is consists of photovoltaic power generators, three phase inverter-type generators, synchronous generators and induction generators. However, synchronous generator is used in this case. The rating of the synchronous generator is shown in Table2.
Test method and results

Regulation tests for output variation of the DG

System voltage fluctuation is caused by output variation (max 800kW) of the synchronous generator set in the generation-A as shown in Fig.6. OCS collects information of every load and generation output by the communication network. OCS calculates optimal voltage profile while changing LPCs output by using collecting the information. OCS orders LPCs to change active power and reactive power output to the calculation results at a 180s interval. Fig.7 shows active power and reactive power output of LPC-C in this test, and these powers are changed according to voltage fluctuation as shown in Fig.8.

Comparing regulation effect of one LPC with three LPCs for load variation

System voltage variation is caused by heavy load set in the load-A (750kW) and load-B (750kW). The system voltage profile was regulated by OCS operation such as the regulation tests. We checked regulation effect with control by using one LPC (LPC-B) and three LPCs as shown in Fig.9. In the case of one LPC, the system voltage rose at 3km distance from substation and the system voltage fell at the end of feeder. In the case of three LPCs, the system voltage falls gradually. At the end of feeder, the system voltage in the case of three LPCs higher than one LPC. From these test results, we checked regulation effect by OCS operation and some LPCs control.

SUITABLE VOLATGE REGULATION METHOD ACCORDING TO INTER-CONNECTION RATE OF DG

Analysis Conditions

We performed the computer simulation about regulating voltage of power distribution system using power system models in residential and commercial area as shown in Fig.10 and Table 3. The voltage regulation methods that we recommend are control voltage rise of DG (Fig.11), SVC control using information of interconnection point voltage (Fig.12), SVC control using information of whole power distribution system and LPC control using ADAPS operation method as shown in above paragraph. Effect of these methods are judged using criterion as shown in following formula.

\[ 95V < V_L < 107V \] (100V system)

Here, \( V_L \) is voltage of low voltage distribution system.

Analysis Result

These methods are evaluated and compared each other according to interconnection rate. Fig.13 shows suitable
voltage regulation method according to interconnection rate as evaluation results. In residential area where DGs are distributed equally, the control using information of whole power distribution system is necessary when interconnection rate is 65% or more.

**Fig.10 Loop Power Distribution System by using LPCs for Study on Suitable Voltage Regulation Methods**

**Table 3 Analysis Conditions**

<table>
<thead>
<tr>
<th></th>
<th>Residential Area</th>
<th>Commercial Area</th>
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</thead>
<tbody>
<tr>
<td><strong>Feeder Capacity</strong></td>
<td>Residential Feeder Model</td>
<td>Commercial Feeder Model</td>
</tr>
<tr>
<td></td>
<td>3.5MVA</td>
<td>3.5MVA</td>
</tr>
<tr>
<td><strong>Feeder Length</strong></td>
<td>3.63km</td>
<td>1.93km</td>
</tr>
<tr>
<td><strong>Analysis Time</strong></td>
<td>at noon</td>
<td>at 7 a.m.</td>
</tr>
<tr>
<td><strong>Load</strong></td>
<td>1451kW 294kVar</td>
<td>143kW 493kVar</td>
</tr>
<tr>
<td><strong>DG Type</strong></td>
<td>Photovoltaic generation</td>
<td>Co-Generation</td>
</tr>
<tr>
<td><strong>DG Output (100%)</strong></td>
<td>2500kW 0kVar</td>
<td>1960kW 949kVar</td>
</tr>
</tbody>
</table>

**Fig.11 Block Diagram for Control Voltage Rise of DG**

**Fig.12 Block Diagram for SVC Control using Information of Interconnection Point Voltage**

**CONCLUSIONS**

Using the real scale experimental equipments, we performed reducing the fluctuation caused by changing load and output of DG, and regulating the system voltage by collecting the system information (system voltage, load and DG) via S&D IF and controlling LPCs. Therefore, we checked that the operation method (by OCS) of ADAPS was effective to the voltage fluctuation at the time of extensive introduction of DG. Moreover, we studied on suitable voltage regulation methods (control voltage rise of DG, SVC control and LPC control) according to interconnection rate of DG by computer simulation about regulating system voltage using power distribution system models in residential and commercial area.

For future work, we will promote a new concept of future power system to cope with more large number of renewable energy resources such as PV system mainly.

**REFERENCES**


