DEVELOPMENT OF VOLTAGE REGULATION METHOD INCLUDING POWER FACTOR CONTROL BY CUSTOMERS IN AUTONOMOUS DEMAND AREA POWER SYSTEM

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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 failure to maintain power quality and supply reliability by conventional power system management.
Especially, in residential, commercial and industrial mixed area of Japan, the distribution system voltage will rise at the end of feeder because of reverse power flow by photovoltaic (PV) generations and capacitors (SC) for power factor control by 6.6kV customers.
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 formation. We try to establish network technology and operation management technology of ADAPS, and identify its effectiveness.
In this paper, we studied voltage regulation method by using Static Var Compensator (SVC) and Step Voltage Regulator (SVR) as power distribution system in transition period from conventional system to ADAPS.

BACKGROUND AND PURPOSE OF ADAPS RESEARCH

We have promoted a study of the Autonomous Demand Area Power System (ADAPS) that is highly efficient power distribution system. Moreover, future power system including ADAPS is called Triple I Power System (Intelligent, Interactive, Integrated: TIPS) and we promoting a study of TIPS in CRIEPI (Fig.1). We think that TIPS is Japanese Type Smart Grid, the research items are operation/control to cope with large penetration of distributed power generations (DGs), ICT infrastructure, evaluation of demand response, demand side management and advanced transmission equipments.
The purpose of the ADAPS is to establish smooth introduction and effective use of the DG. In the research of ADAPS, we have established network technology and operation management technology of ADAPS including system in transition period, and identify its effectiveness.
In this paper, we present that we carried out computer simulation by using developing analysis and estimation tool, and studied voltage regulation method by using SVC (Static Var Compensator) and SVR (Step Voltage Regulator) as power distribution system in transition period from conventional system to ADAPS.

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.

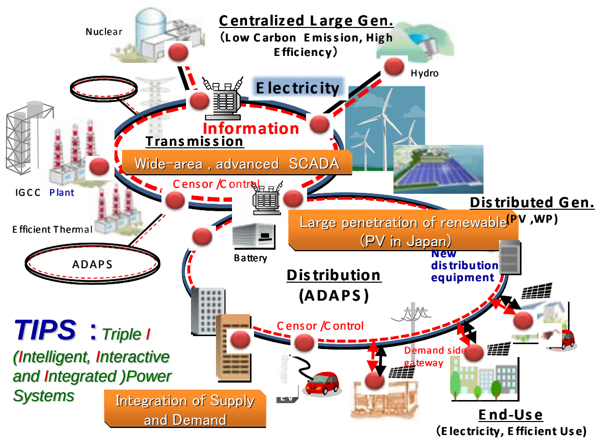

Fig.1 Expected future power system (TIPS)

Configuration of ADAPS

ADAPS may be in the loop formation by using Loop Power Flow Controller (LPC) as shown in Fig.2 (c), in addition to the conventional tree branch formation as shown in Fig.2 (b). LPC controls power flow and voltage between loops. Operation Control System (OCS) and Supply and Demand Interface (S&D IF) per every customer will be installed for information exchange between supply and demand sides. The function of S&D IF adds load and photovoltaics output control to the basic function of meter, and is highly intelligent smart meter. OCS (central unit) aims for the power flow control of whole of ADAPS. The communication network is consists of optical fibers and developed programs.

Power distribution system in transition period from conventional system to ADAPS

Currently, 6.6kV power distribution system of Japan is shaped like tree branch as shown in Fig.2 (a). Distribution automation system controls section switches in order to perform fault operation by communication system that is consists of metal line or/and power line carrier system. Each feeder connects adjoining feeders by using usually open switches. Only long feeder has SVR as shown in Fig.3 in order to regulate the system voltage.

In transition period to ADAPS, power distribution system will be shaped like tree branch as shown in Fig.2 (b). Distribution automation system will control section switches in order to perform fault operation, and will control SVR and SVC in order to regulate the system voltage from sensor information by communication system that is consists of metal line or/and optical fibers.

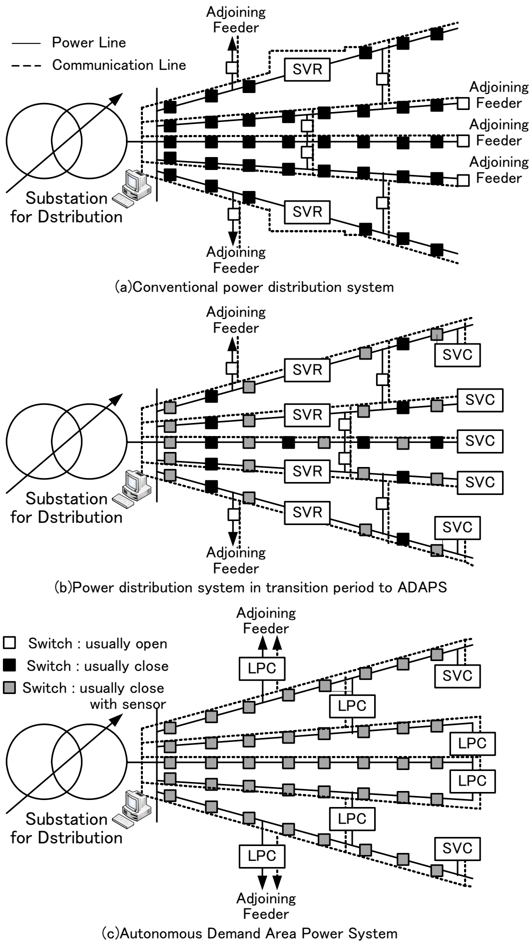

Fig2. Transition process of power distribution system

In ADAPS, power distribution system will be shaped like loop or mesh as shown in Fig.2 (c) by using LPCs. Distribution automation system will control section switches, LPC and SVC in order to regulate the system voltage and perform fault operation from sensor information, by high-speed communication system that is consists of optical fibers.

Fig.3 Photograph of step voltage regulator (SVR)

STUDY ON VOLTAGE REGULATION METHOD IN TRANSITION PERIOD

Distribution model and load model

Distribution model is shown in Fig.4. The feeder length is 3.65km, the feeder capacity is 4MVA, many 200V customers are connected to every node, two 6.6kV customers are connected to middle point (A) and end (B) of the feeder, SVC connected to A and/or B, SVR is connected to A.

The feeder load model of 200V customers and 6.6kV customers, and PV output at fine day are shown in the upper half of Fig.5. The 6.6kV customer load model is shown in the lower half of Fig.5, and the load consists of single-phase 200V load and three-phase 400V load. Moreover, capacitor for power factor control is 100kVar * 3 sets with automatic SC control function.

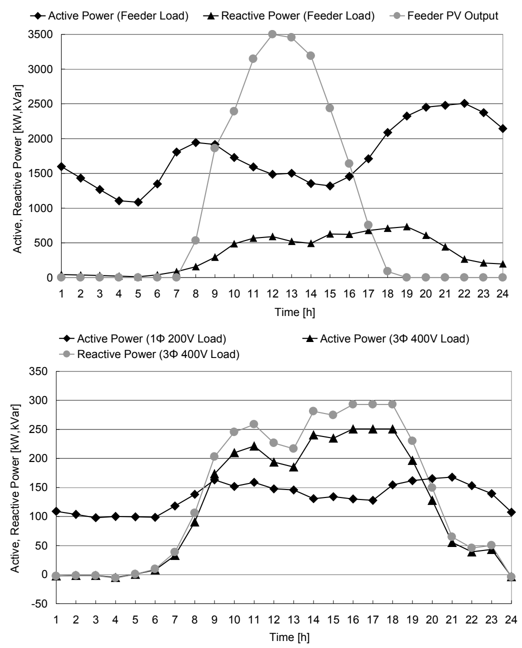

Fig.5 Feeder load and customer load curve

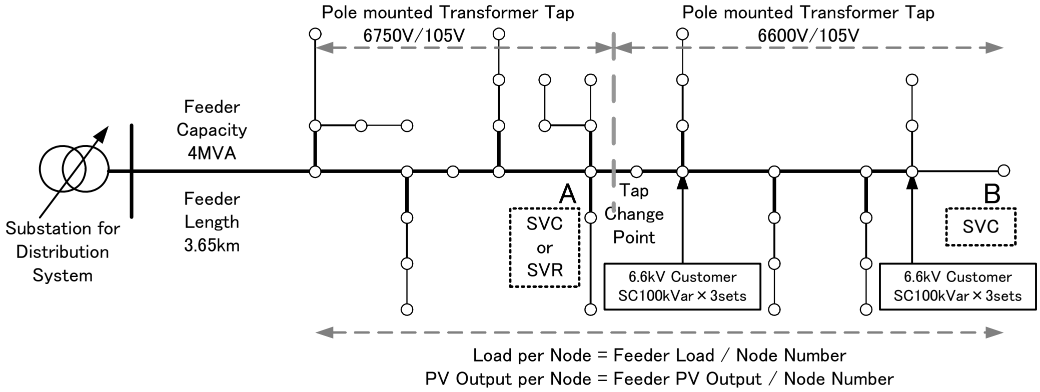

Fig.4 Residential, commercial and industrial distribution model for comparing voltage regulation method

The Power factor control method by 6.6kV customers is shown in Fig.6. Original Load is lag (example PF=0.8) and the power factor is improved by switching capacitor (SC). SC is controlled between two red lines of target power factor. Moreover, all SC is open if the active power load is very low.

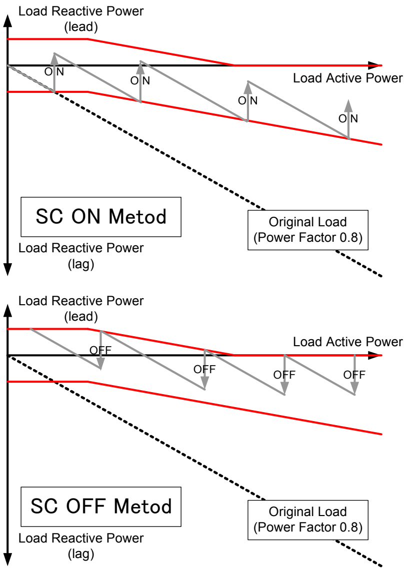

Fig.6 Power factor control method by customer

Simulation results

Fig.7 shows feeder load curve in the case of SC off, SC on, SC schedule control and automatic SC control when interconnection rate of PV is 40%. When the SCs are off, reactive power is lag all day. When the SCs are on, reactive power is lead most all day. When the SCs control according to schedule, reactive power is lead for several hours. When the SCs control automatically, reactive power is almost 0kVar.

Fig.8 shows low voltage at the end of the feeder when interconnection rate is 40%. The system voltage rises in the daytime because of the PV generation output, and rise toward morning because of the capacitors. Even if customers control the SCs automatically, the distribution system voltage may rise slightly and Japanese type PV output decrease. Because the PV system has function of automatic voltage regulation, and by this function generate reactive power and reduce output when voltage at the interconnection point exceed upper limit voltage.

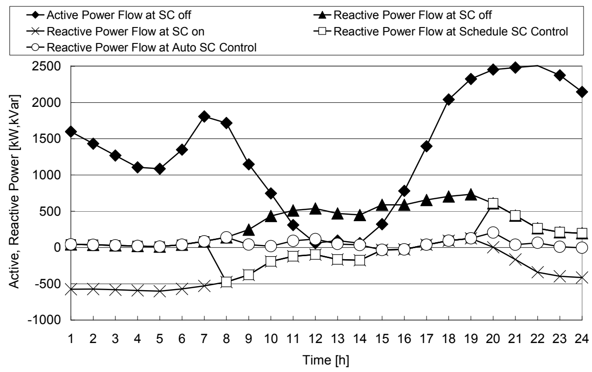

Fig.7 Active and reactive power flow of feeder

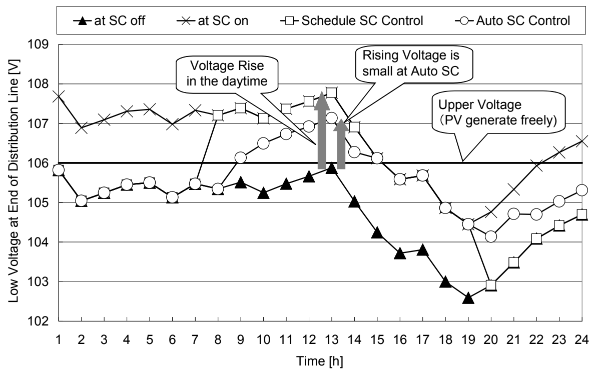

Fig.8 Low Voltage at End of Distribution Line

Comparing voltage regulation method

In case(1)(2)(4) of Table1, distribution system voltage exceed proper range, nevertheless the system operation regulates the system voltage by using SVC and SVR using the voltage information at the connection point.

Table 1 Results of comparing voltage regulation method

case	Control apparatus	Control method	Connection point	Combination apparatus	Voltage regulation (maximum interconnection rate in proper voltage)	Distribution loss [kWh]	Required capacity of SVC [kVA]
(1)	SVC	using voltage information at connection point	middle point (A)	-	Voltage rise (20%)	-	-
(2)	SVC		end (B)	-	Voltage rise (0%)	-	-
(3)	SVC		middle point (A), end (B)	-	Regulated voltage (100% or more)	1036	1757
(4)	SVC		end (B)	SVR (A)	Voltage rise (40%)	-	-
(5)	SVC	using voltage information from some sensors installed in distribution line	end (B)	-	Regulated voltage (100% or more)	873	1740
(6)	SVC		end (B)	SVR (A)	Regulated voltage (100% or more)	684	1044

interconnection rate = PV capacity / Feeder capacity *100

The upper limit voltage is 106V because upper limit is voltage 107V by law and the system voltage rise 1V in low voltage distribution line.

On the other hand, In case(3) of Table1, the distribution system voltage are regulated by SVC and SVR using the voltage information at the connection point, and In case(5)(6) of Table1, the distribution system voltage are regulated by SVC and SVR using the voltage information from some sensors installed in the distribution line. Communication system is required in these case, but cost of communication system is cheaper than cost of SVC.

Moreover, we compared case(3)(5)(6) on distribution loss and required capacity side, and case(6) is best from these results.

CONCLUSION AND FUTURE WORK

In this paper, we studied voltage regulation system in transition period from conventional system to ADAPS when many PV systems interconnect to distribution system. We cleared that the system using SVR and SVC from the voltage information using some sensors installed in the distribution line was suitable. In the future, we will clear most suitable system to regulate system voltage at cloudy day, and study the method to regulate system voltage including low voltage distribution line.

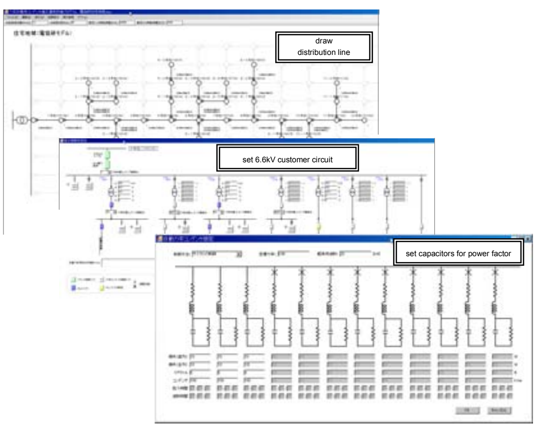

Fig.9 Analysis tool for power distribution system

Fig.9 shows an analysis program that we are developing to estimate voltage regulation method. We can simulate power distribution line, transformer of substation, SVR, SVC, LPC, SC and DG by using this program. The program is called "CALDG" and is used many electric power companies in Japan.

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