COORDINATED OPERATION OF TSO, DSO AND CONSUMERS IN VOLTAGE MANAGEMENT IN CASE OF INTERCONNECTING LARGE AMOUNT OF PV

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ABSTRACT

In Japan, power company TSO in each region has been operating the transmission system of voltage 66kV or more, DSO has been operating the distribution system of following voltage 6.6kV. In addition, Customers have been operating the distributed power generations of the customer.
Before photovoltaic generations (PV) becoming large amount of interconnection to the power system, TSO, DSO and customer was little need for cooperation in the voltage management. However, in case of becoming large amount, in social cost and technical aspects, TSO, DSO and customers came out needs to be coordinated. In this paper, the voltage control method of transformer in distribution substation (DSS) that adopted as equipment of the current state are schedule control, scalar type load drop compensation (LDC) and vector type LDC. We evaluated the effect of the system voltage regulation about these voltage control method and clear most suitable voltage control method, in order to clarify the coordination methods and the roles of TSO, DSO and customers. As a result, as a countermeasure to the PV interconnection of the order of 40% relative to the peak power of the load, in the control of the transformer of DSS, it was the most effective control method is vector type LDC. Further, by making the power factor (pf) constant control of PV is applied, it was found to be further corresponding to the connection of a large amount of PV.

INTRODUCTION

In Japan, power company TSO in each region has been operating the transmission system of voltage 66kV or more, DSO has been operating the distribution system of following voltage 6.6kV. In addition, Customers have been operating the distributed power generations of the customer.
Before photovoltaic generations (PV) becoming large amount of interconnection to the power system, TSO, DSO and customer was little need for cooperation in the voltage management. However, in case of becoming large amount, in social cost and technical aspects, TSO, DSO and customers came out needs to be coordinated.
In this paper, the voltage control method of transformer in distribution substation (DSS) that adopted as equipment of the current state are schedule control [Fig.2], scalar type LDC [Fig.3] and vector type LDC [Fig.4]. We evaluate the effect of the system voltage regulation about these voltage control method and clear most suitable voltage control method, in order to clarify the coordination methods and the roles of TSO, DSO and customers.

VOLTAGE MANAGEMENT IN JAPAN

Voltage control of power transmission line

Voltage control of the power transmission lines of voltage 66kV is carried out using a control of transformer of power transmission substation or phase modifying equipment.

Transformer voltage control of power distribution substation

Figure1 shows the configuration of the DSS and the distribution system.

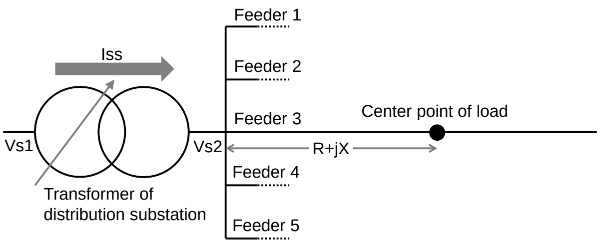

Fig.1 Explanatory diagram of the voltage control method

Schedule control

Figure2 shows an example of the operation of the scheduled control. Voltage (Vs2) at each time in figure2 is the target voltage of the transformer secondary voltage of the DSS. The target voltage is determined by the historical load current.

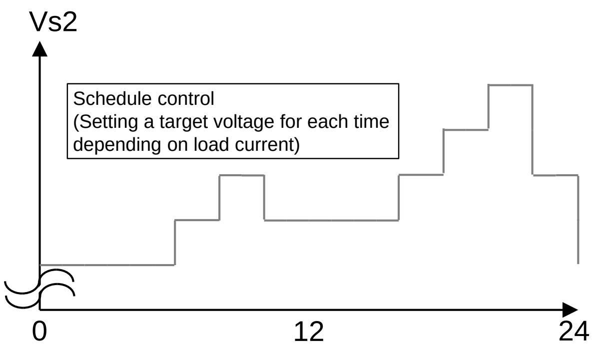

Fig.2 Schedule control

Scalar type load drop compensation

Figure3 shows an example of the operation of the scalar type LDC. In view of the load current and the impedance of the distribution line, it is controlled to be the maximum voltage at the time of the maximum current and be the minimum current at the minimum current.

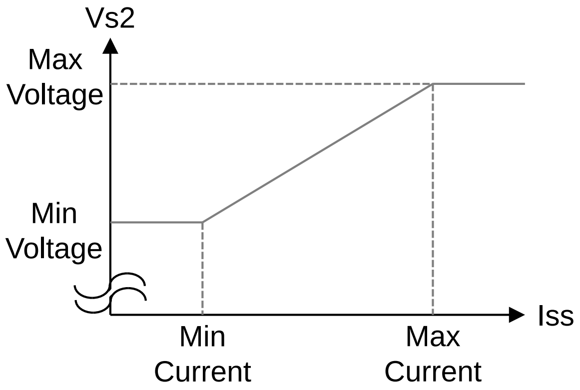

Fig.3 Scalar type load drop compensation

Vector type load drop compensation
Figure4 shows an example of the operation of the vector type LDC. Toward the end of the distribution line from the transformer secondary voltage of the DSS, the voltage drop by the impedance of the distribution line and the load current. The voltage of the load center point determined from this relationship is controlled to maintain the target voltage.

Voltage control of power distribution line
Voltage control of the power distribution lines of voltage 6.6kV is carried out using a control of step voltage regulator equipped in the middle of the distribution line.

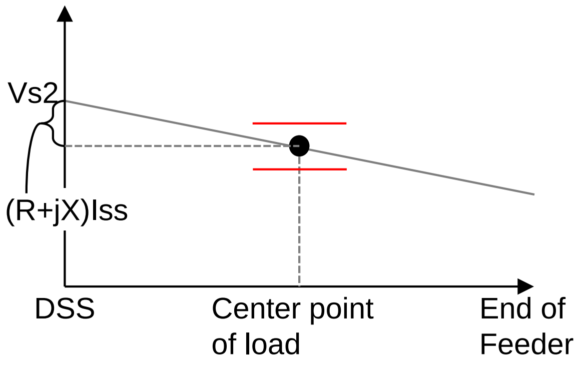

Fig.4 Vector type load drop compensation

ANALYSIS

Analysis Tool

We analyzed by using the distribution system comprehensive analysis tool that was developed in our laboratory (CRIEPI).
Fig.1 shows drawing window of MV power distribution system. We can draw MV power distribution system by using graphical user interface(GUI) on mesh (100*100), and set substation voltage control for distribution system, loads, generators (PV, WG, Co-gene etc.) and voltage control equipment (SVR[Step Voltage Regulator], SVC, STATCOM etc.).
The line impedance and distance of MV power distribution line can be set by GUI and line impedance database. The database is made based on the actual condition of the use for each electric power company. There are two kinds of load. One is the load which change in time and another is the MV customer load with capacitors for improving pf. The setting of the load which changes in time is specified by csv files made by Microsoft Excel. There are two kinds of generator. One

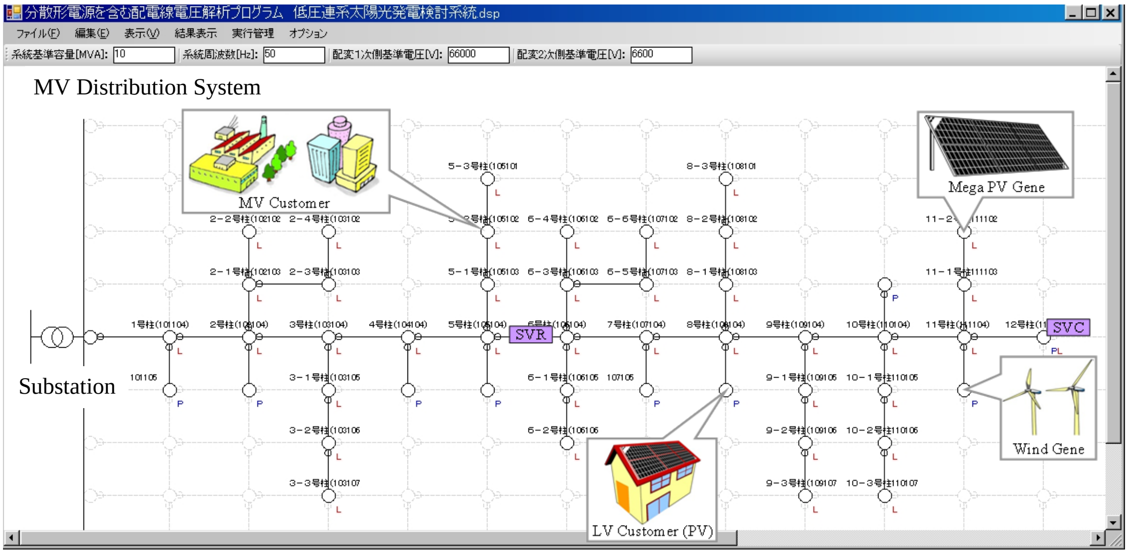

Fig.5 Comprehensive analysis tool of power distribution system

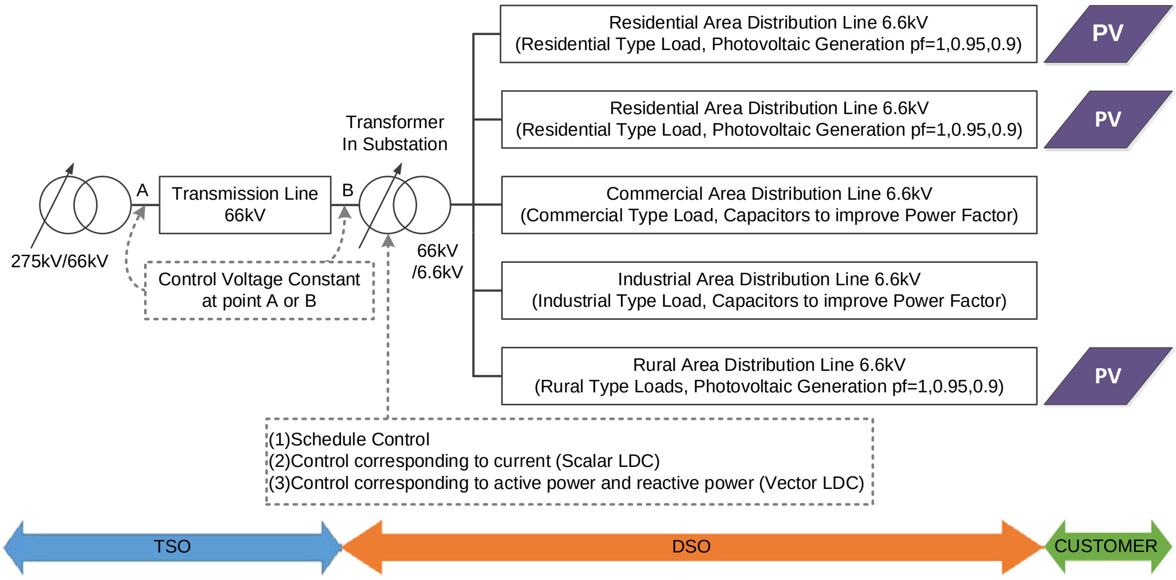

Fig.6 Power system model for study of voltage management

is the generator which changes in time and another is the PV system interconnected to LV line. The setting of generator which changes in time is specified by csv files. The settings of the voltage control equipment are the rating voltage, the rating capacity, the threshold value and the timer value. All values are input by GUI.

Analysis method

From the power transmission substation of 275kV / 66kV, via the transmission line of the 20km length of the voltage 66kV, DSS is connected. From the transformer of 66kV / 6.6kV, five distribution lines are drawn. Residential, commercial, industrial and rural areas are supplied by these distribution lines. Detached houses and PV interconnect to the distribution line in the residential area and the rural area. Commercial building and factory interconnect to the distribution line in the commercial area and the industrial area. DSO installs the step voltage regulator to the distribution line in the rural area.

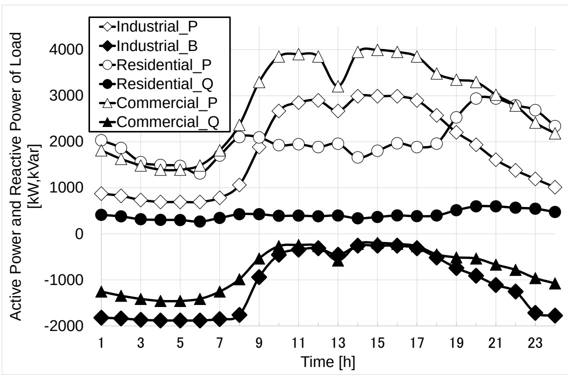

Fig.7 Load curve of each area

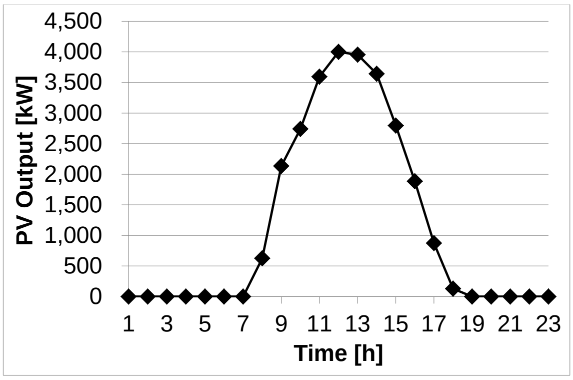

Fig.8 PV output curve

Parameters of study are the control method of transmission line, the control method of transformer in the DSS and operation pf of PV.
Fig.7 shows the load (active and reactive power) curve of each area and fig.8 shows the PV output curve.

Analysis results

The analysis results are shown in fig.9, fig.10, table1 and table2.
Fig.9 shows the change of the voltage of each feeder end when the interconnection amount of PV is 40%. The distribution line in the residential areas overs the upper limit of the voltage.
Fig.10 shows the change of the voltage of feeder end in the residential areas, which controlled by the schedule control, the scalar type LDC, the vector type LDC and the vector type LDC with the PV pf control when the interconnection amount of PV is 60%. The most effective control method is the vector type LDC.
Table1 shows frequency of voltage departing from the appropriate range by applying each the voltage control of the transmission line and the voltage control of the

transformer in the DSS according to the interconnection amount of PV. If we comprehensively evaluate the results from the standpoint of the DSO, vector LDC is the most effective.

Table2 shows frequency of voltage departing from the appropriate range by applying each voltage control of transmission line and the vector LDC according to operating pf 0.95, 0.9. If we comprehensively evaluate the results from the standpoint of the customers, operating pf 0.95 is the most effective. To cooperate with the DSO, TSO will not be controlled to a constant the voltage of downstream of the transmission line. It is necessary to control the voltage of upstream of the transmission line at the constant level.

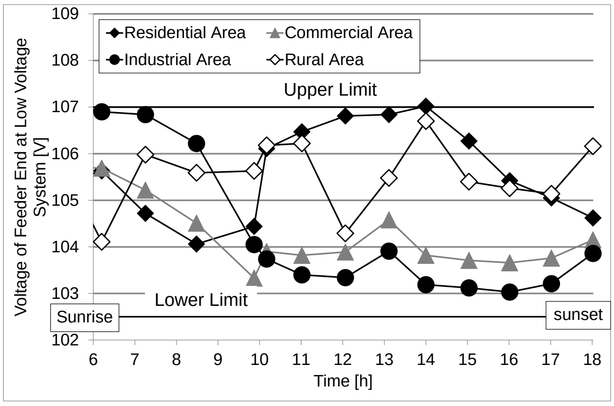

Fig.9 Analysis results of distribution line voltage

CONCLUSION

As a result, as a countermeasure to the PV interconnection of the order of 40% relative to the peak power of the load, in the control of the transformer of DSS, it was the most effective control method is the vector type LDC. Further, by making the pf constant control of PV is applied, it was found to be further corresponding to the interconnection of a large amount of PV.

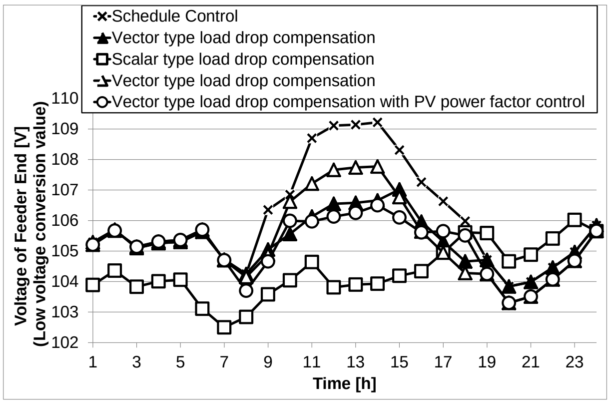

Fig.10 Comparison of control method (analysis results)

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[1] S.Uemura, M.Takagi: "Development of Comprehensive Analysis Tool of power distribution system Vol.1 -Calculation Program for Distribution System and Customer System to Correspond Large Penetration of PV Generation-", *CRIEPI Report*, R11025 (2012) [in Japanese]

[2] S.Uemura "Estimation and Measure by Comparing Voltage Regulation Method of Transformer for Distribution in Substation System with PV Large Penetration", *CRIEPI Report*, R14021 (2015) [in Japanese]

Table1 Frequency of voltage departing from appropriate range by all method

Votage Control of Transmission Line	Votage Control of Transformer of Substation		Frequency of Voltage Departing from Appropriate Range (Left:Low, Right:high)													
		PV Connection Rate [%]	0		20		40		60		80		100		120	
No consideration	Schedule Control	Reference of Scalar LDC	0	0	0	1	0	6	0	12	0	13	0	16	0	17
		Reference of Vector LDC	0	0	0	1	0	5	0	9	0	13	0	15	0	17
Constant Voltage of Downstream Side of Transmission Line	Scalar LDC		0	0	0	0	10	0	15	4	16	5	19	6	19	6
	Vector LDC		0	0	0	0	0	1	4	4	4	9	4	11	5	14
Constant Voltage of Upstream Side of Transmission Line	Scalar LDC		0	0	1	0	12	0	15	4	15	5	20	6	20	6
	Vector LDC		0	0	0	0	0	0	0	8	7	9	7	11	9	15

Table2 Frequency of voltage departing by adding pf control of PV

Votage Control of Transmission Line	Voltage Control		Frequency of Voltage Departing from Appropriate Range (Left:Low, Right:high)														
	Votage Control of Transformer of Substation	PV Output Power Factor	PV Connection Rate [%]	0		20		40		60		80		100		120	
Constant Voltage of Downstream Side of Transmission Line	Vector LDC	0.95		0	0	0	0	0	0	0	0	0	3	0	5	0	6
		0.9		0	0	0	0	0	0	2	0	2	2	2	2	1	5
Constant Voltage of Upstream Side of Transmission Line		0.95		0	0	0	0	0	0	0	0	0	1	1	4	1	10
		0.9		0	0	0	0	0	0	0	0	1	0	2	3	1	2