DEVELOPMENT OF VOLTAGE REGULATION METHOD CONSIDERING MUTUAL SMOOTHING EFFECT OF PV IN POWER DISTRIBUTION SYSTEM

Katsuki KAWAHARA Shigeru MIYASHITA Satoshi UEMURA Hiromu KOBAYASHI
The Central Research Institute of Electric Power Industry – Japan
kawahara@criepi.denken.or.jp s-miya@criepi.denken.or.jp s-uemura@criepi.denken.or.jp hiromuk@criepi.denken.or.jp

ABSTRACT

There is a possibility that problems such as the distribution line voltage rise and fluctuation occur when a large number of PV interconnection to the distribution system. In this paper, we report that the effects of the smoothing effect and the PV output fluctuation give to the voltage management in distribution system. In addition, the effectiveness of the proposed method for improvement of voltage regulation effect is presented.

INTRODUCTION

In recent years, the widespread use of photovoltaic (PV) is progressing, there is a possibility that problems such as the distribution line voltage rise occurs when a large number of PV interconnection to the distribution system. Further, if PV output fluctuation is large, it affects the number of SVR operations. In addition, it is difficult to maintain the suitable voltage because SVR cannot follow the fluctuation of the system voltage.

In this paper, we report that the effects of the smoothing effect and the PV output fluctuation give to the voltage management in distribution system.

PRESENT STATUS AND PLOBLEMS OF VOLTAGE MANAGEMENT IN JAPAN

In Japan, the voltage is controlled within 101 ± 6V at low voltage system. Voltage management system regulates the sending voltage of feeder according to load curve at substation. If the voltage drop of the power distribution lines is large, a SVR installed in the middle of distribution line compensate for the voltage drop.

Fig.1 shows structure of SVR. SVR consists of control transformer, on-load tap changer and line drop compensator (LDC). By detecting the voltage drop from SVR output terminal to the predetermined reference point of distribution line, SVR regulates the voltage of the reference point to be constant by controlling the tap position.

However, SVR operation might not follow the voltage fluctuation in large penetration of PV. Because the operating time of SVR is for 45 ~ 120(sec), the output power of PV changes rapidly. Furthermore, there is possibility of increased the number of SVR operations and shortened lifetime of SVR.

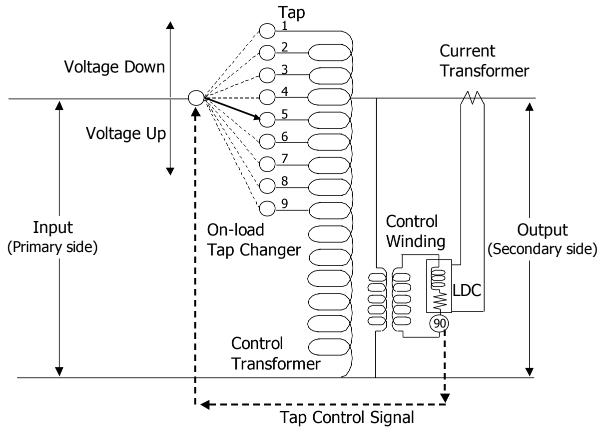


Fig.1 Structure of SVR mode

POWER DISTRIBUTION SYSTEM MODEL AND SOLAR RADIATION INTENSITY

In order to analyse the influence of large penetration of PV on voltage management in power distribution system, we have modelled four types of power distribution system classified according to load density in Kyushu area of Japan. Fig.2 shows the simulation model in this case, in order to focus on influence of power fluctuation and smoothing effect on SVR operations and voltage management in power distribution system. The length of trunk line is about 10km and a SVR is installed.

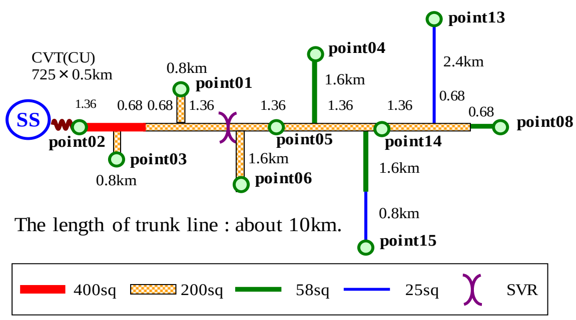


Fig.2 Power distribution system model

We have created the PV output data based on the measurement data of solar radiation intensity. Fig.2 shows layout of pyrheliometers installed to 15 locations in the area of 10km × 4km. They are located at regular space (1 ~ 5km), in order to evaluate of smoothing effect of PV output power.

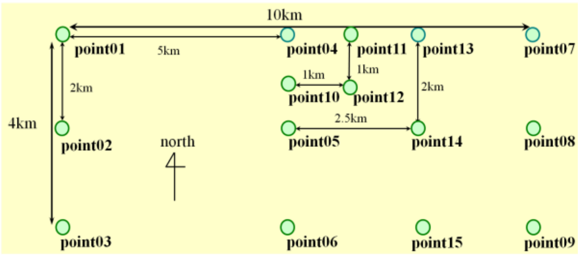


Fig.3 Layout of pyrheliometers

As an example of measurement data, Fig.4 shows the changes of solar radiation intensity on mostly sunny day and large fluctuation day at point01, and the average of solar radiation intensity at point01 ~ 15. The fluctuation of average solar radiation intensity is smaller than the fluctuation at point01. It means the smoothing effect can be expected in the size of distribution system.

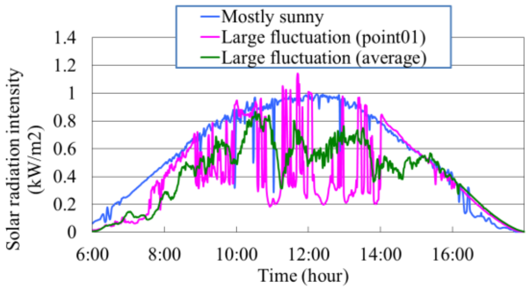


Fig.4 Changes of solar radiation intensity

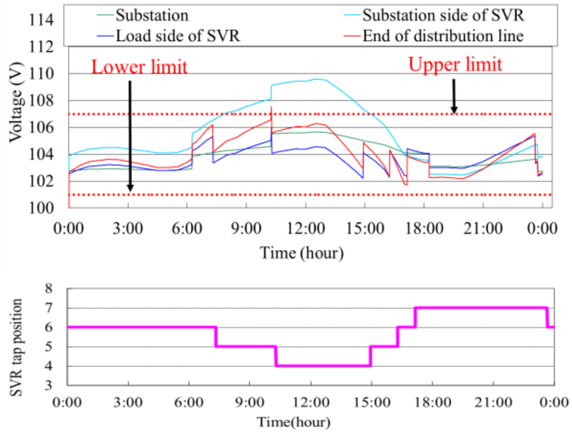
SIMULATION CONDITIONS

We have analysed the voltage of power distribution system and SVR operation to set the amount of PV interconnection and daily load peak as parameters in Fig.2, and examined the maintenance of the suitable voltage considering the voltage drop from a pole transformer to receiving equipment (101 ~ 107V at low voltage system).

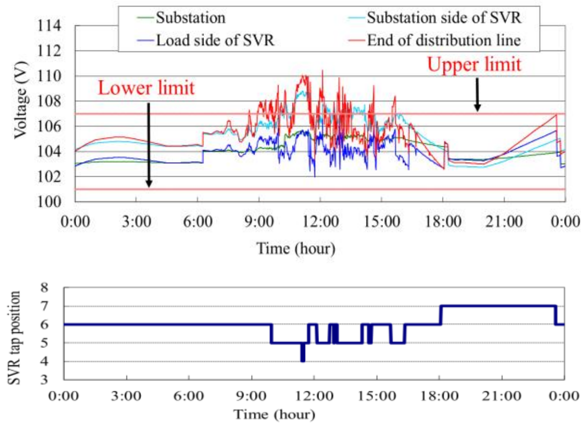
At this time, in order to analyse the influence of the smoothing effect and PV output fluctuation, we have carried out the numerical simulation of the relationship between the system voltage and the amount of PV interconnection in three cases. (a) Mostly sunny (no large PV output fluctuation), (b) Large PV output fluctuation with smoothing effect (the PV output in Fig.3 corresponded to 10 points on power distribution system model in Fig.2.), and (c) Large PV output fluctuation without smoothing effect (the PV output at point01 was applied to all points). SVR operation timer is set to 45(sec), and target voltage of SVR is set to 106.7(V).

SIMULATION RESULTS

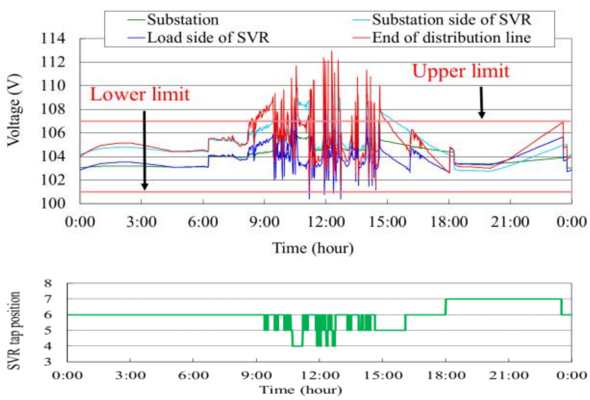
Fig.5 shows the results of the system voltage and SVR operation at 3,000 kW in PV interconnection. We could confirm that under the influence of the PV output fluctuation, the number of SVR operation greatly increased. Fig.5 also shows the voltage fluctuation over appropriate range, because SVR operation cannot follow the PV output fluctuation.



(a) Mostly sunny (no fluctuation)



(b) Large output fluctuation considering smoothing effect



(c) Large output fluctuation not considering smoothing effect

Fig.5 Changes of system voltage and SVR operation in PV interconnection (PV: 3,000kW)

Table1 shows maximum and minimum system voltage and the number of SVR operations in three cases of (a), (b) and (c). When the results of the case of (c) were compared with the case of (a), the number of SVR operations greatly increased at more than 1,000kW in PV interconnection (2 -> 22). On the other hand, in the case of (b), there were no significant changes in the number of SVR operations and system voltage up to 2,000kW in PV interconnection. The maximum capable amount of PV interconnection was about 500kW in all cases of (a), (b) and (c).

Table1 Changes of system voltage and SVR operation in PV interconnection (PV: 3,000kW)

(a) Mostly sunny (no fluctuation)

Peak load / Sending voltage	System voltage/ SVR operation	The amount of PV interconnection (kW)						
		0	250	500	1,000	1,500	2,000	3,000
Light-load season 2,593kW 6,720V	Maximam (V)	105.6	106.4	107.2	107.8	108.6	109.0	111.3
	Minimam (V)	101.0	101.0	101.0	100.9	100.9	100.9	100.9
	The number of SVR operations	0	0	0	2	2	4	4
Heavy-load season 3,940kW 6,840V	Maximam (V)	106.8	106.8	106.8	106.8	107.3	108.7	109.6
	Minimam (V)	101.0	101.0	101.0	100.8	100.7	100.7	100.8
	The number of SVR operations	2	2	2	2	2	4	6

(b) Large output fluctuation considering smoothing effect

Peak load / Sending voltage	System voltage/ SVR operation	The amount of PV interconnection (kW)						
		0	250	500	1,000	1,500	2,000	3,000
Light-load season 2,593kW 6,720V	Maximam (V)	105.6	106.5	107.4	108.3	108.6	110.1	111.8
	Minimam (V)	101.0	101.4	101.4	101.2	101.2	101.1	101.0
	The number of SVR operations	0	0	0	2	2	4	12
Heavy-load season 3,940kW 6,840V	Maximam (V)	106.8	106.8	106.8	107.1	106.9	108.1	110.2
	Minimam (V)	101.0	101.0	101.0	100.6	100.7	100.7	100.6
	The number of SVR operations	2	2	2	4	4	4	16

(c) Large output fluctuation not considering smoothing effect

Peak load / Sending voltage	System voltage/ SVR operation	The amount of PV interconnection (kW)						
		0	250	500	1,000	1,500	2,000	3,000
Light-load season 2,593kW 6,720V	Maximam (V)	105.6	106.6	107.5	108.7	109.2	110.7	113.9
	Minimam (V)	101.0	101.4	101.4	101.2	101.2	100.4	100.5
	The number of SVR operations	0	0	0	4	2	12	46
Heavy-load season 3,940kW 6,840V	Maximam (V)	106.8	106.8	106.8	107.4	109.0	109.0	112.6
	Minimam (V)	101.0	101.0	101.0	100.1	100.3	99.7	99.0
	The number of SVR operations	2	2	2	22	18	20	58

□ : 101～107V □ :107~109V , less than101V □ : more than 109V

PROPOSAL OF IMPROVED VOLTAGE REGULATION

In order to improve voltage regulation effect, SVR tap width was changed 120(V) to 60(V). Fig.7 shows changes of system voltage in PV interconnection in case of (c). Table2 shows maximum and minimum system voltage and the number of SVR operations in three cases of (a), (b) and (c).

As a result, the amount of deviation of the voltage was reduced. In case of (b), the capable amount of PV interconnection was expanded to 2,000kW. On the other hand, the number of SVR operations greatly increased (14->44 at 2,000kW). Since the increase of the number of SVR operations can affect the lifetime of the SVR, it must be improved tap switching device.

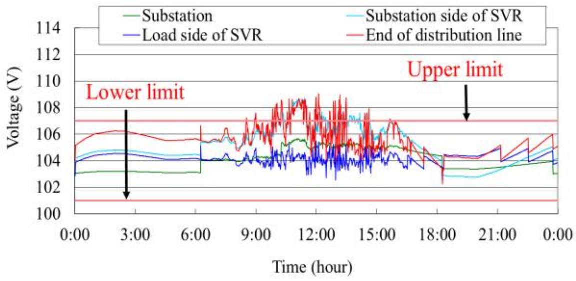


Fig.7 Changes of system voltage in PV interconnection in case of (c)
(SVR tap width: 120V ->60V, PV: 3,000kW)

Table2 Changes of system voltage and SVR operation in PV interconnection (PV:3,000kW)

(a) Mostly sunny (no fluctuation)

Peak load / Sending voltage	System voltage/ SVR operation	The amount of PV interconnection (kW)						
		0	250	500	1,000	1,500	2,000	3,000
Light-load season 2,593kW 6,720V	Maximam (V)	105.1	105.2	105.2	105.5	105.8	106.2	109.2
	Minimam (V)	101.0	101.0	101.0	101.0	101.0	101.0	101.0
	The number of	1	3	3	5	7	9	11
	SVR operations	2	4	4	6	8	8	6
Heavy-load season 3,940kW 6,840V	Maximam (V)	105.8	105.8	106.0	105.9	106.5	107.1	108.2
	Minimam (V)	101.0	101.0	101.0	101.0	101.0	101.0	101.1
	The number of	7	5	7	7	9	11	13
	SVR operations	10	8	8	8	14	14	15

(b) Large output fluctuation considering smoothing effect

Peak load / Sending voltage	System voltage/ SVR operation	The amount of PV interconnection (kW)						
		0	250	500	1,000	1,500	2,000	3,000
Light-load season 2,593kW 6,720V	Maximam (V)	105.0	105.2	105.2	106.6	106.1	106.9	108.3
	Minimam (V)	101.0	101.0	101.0	101.0	101.0	101.0	100.9
	The number of	0	0	2	4	8	6	26
	SVR operations	2	4	4	6	16	20	26
Heavy-load season 3,940kW 6,840V	Maximam (V)	105.7	105.7	105.7	106.0	106.1	106.6	107.5
	Minimam (V)	101.0	101.0	101.1	101.1	101.1	101.0	101.1
	The number of	8	6	6	10	10	22	32
	SVR operations	10	6	8	16	16	24	44

(c) Large output fluctuation not considering smoothing effect

Peak load / Sending voltage	System voltage/ SVR operation	The amount of PV interconnection (kW)						
		0	250	500	1,000	1,500	2,000	3,000
Light-load season 2,593kW 6,720V	Maximam (V)	105.0	105.1	105.4	106.8	107.9	108.8	111.2
	Minimam (V)	101.0	101.0	101.0	100.8	100.1	99.6	99.5
	The number of	0	0	2	10	42	42	72
	SVR operations	2	4	4	14	20	46	48
Heavy-load season 3,940kW 6,840V	Maximam (V)	105.7	105.7	105.7	107.0	108.3	109.1	111.0
	Minimam (V)	101.0	101.0	101.0	100.3	99.8	99.4	97.5
	The number of	8	8	8	24	58	60	100
	SVR operations	10	8	14	22	36	42	64

□ : 101～107V □ :107~109V , less than101V □ : more than 109V

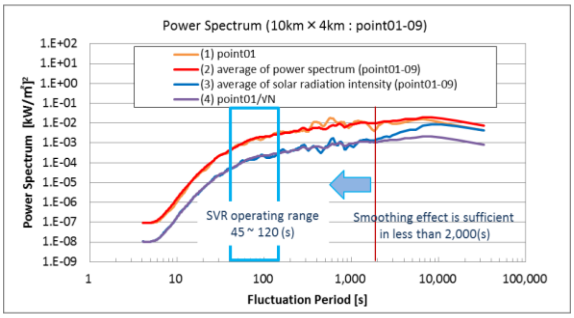
SPECTRAL ANALYSIS OF SOLAR RADIATION INTENSITY

In order to confirm the degree of smoothing effect of PV output fluctuations, we have analysed the power spectrum of solar radiation intensity of each point in Fig.3.

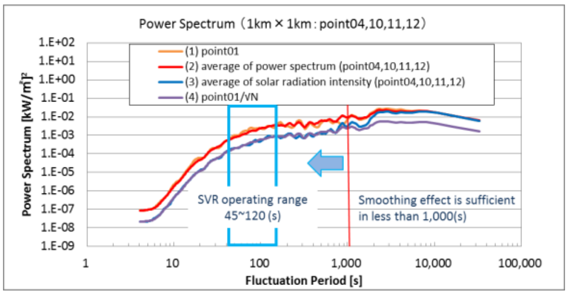
Fig.9 shows four cases of the power spectrum of solar radiation intensity; (1) power spectrum at single point, (2) the average value of the power spectrum at all measurement points, (3) power spectrum of the average of solar radiation intensity at all measurement points, (4) the power spectrum of (1) divided √ N (N is the number of points).

When smoothing effect is sufficient, the power spectrum of (1) becomes to be (4). Fig.9 shows smoothing effect of power spectrum of solar radiation intensity can be evaluated within SVR operating time on the scale of distribution system.

When the lifetime of SVR and the number of SVR operations were evaluated, we confirmed that it is necessary to consider the smoothing effect of PV output by means of the spectral analysis. However, power distribution systems have various shapes, the degree of smoothing effect is different.



(a) Measurement area: 10km×4km (point01-09)



(b) Measurement area: 1km×1km(point04,10,11,12)

Fig.9 Power spectrum of solar radiation intensity

CONCLUSION

We confirmed that under the influence of the PV output fluctuation, the number of SVR operations and the amount of deviation of system voltage greatly increased. However, smoothing effect of PV output fluctuations reduced them to some degree.

By changing SVR tap width 120(V) to 60(V), SVR operation improved voltage regulation effect and the amount of deviation of the voltage was reduced.

We have analysed the power spectrum of solar radiation intensity. Smoothing effect can be evaluated within SVR operating range on the scale of distribution system. When the life of SVR and the number of SVR operations were evaluated, it is necessary to consider the smoothing effect of PV output.

REFERENCES

[1] T.Nanahara, 2006, "Smoothing Effects of photovoltaic power generation", *CRIEPI Report*, R05014, 2006.6 (in Japanese)

[2] S.Uemura, 2012, "Development Comprehensive Analysis Tool of Power Distribution System Vol.1 ", *CRIEPI Report*, R11025, 2012.6 (in Japanese)

[3] K.Kawahara, A.Oono, S.Uemura, 2012, "Influence of Large Penetration of Photovoltaic Generation on Voltage Management in Power Distribution system", *Institute of Electrical Engineers of Japan, Electric power Energy section convention*. No. 125 (in Japanese)