A STUDY ON THE PLACEMENT AND MODEL SELECTION OF VOLTAGE REGULATORS IN DISTRIBUTION NETWORK

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ABSTRACT

When high-capacity renewable PV systems are interconnected to the distribution system, there is a problem that the voltage of the distribution system exceeds the proper value. However, there is no guidance in selection and placement of the voltage regulators to solve this problem effectively. Therefore, the voltage control effect by the arrangement and combination of voltage regulators are verified by simulation analysis. Based on the results, installation guidelines of voltage regulators are clarified.

INTRODUCTION

When high-capacity renewable PV systems are interconnected to the distribution system, reverse power flow is generated from the surplus power of PVs, the voltage on the downstream (demand) side of the distribution system is increased. Further, when the PV output is varied, the distribution voltage fluctuates; the voltage management of the distribution system becomes more difficult. This phenomenon has become the obstacle to expand the installation of the PVs to the distribution system.

Installation of the voltage regulators to the distribution system can be cited as one solution to this problem. However, there are no guidelines for the type selection and installation location and equipment capacity of the voltage regulators.

In this paper, in order to clarify the installation of guidelines of the voltage regulator to the distribution system, the simulation analysis of the location and the combination of the voltage regulators to maintain the distribution voltage within the proper value is verified. Voltage regulators are directed to the five types of SVR, TVR, ShR, STATCOM, and Battery. The configuration for the distribution system is interconnected in series or in parallel; the control variable is a continuous or discrete.

SETTING OF ANALYSIS CONDITIONS

In this chapter, indicating the setting conditions and the modeling method of the distribution system, load, and voltage regulators to be used for simulation analysis.

Distribution system model

Distribution system model is directed to a generalized Japanese residential area. 6.6kV high-voltage (HV) distribution system model is shown in Figure 1. In this model, the distribution voltage has exceeded the appropriate value by the PVs installation and the line impedances are set to compare the control effect of voltage regulators under the same distribution system condition. In residential areas, power distribution voltage is affected by the distribution of the installation rate and the installation location of PVs. In this study, the base case model, install the equally PV to 50% of detached houses, distribution system voltage exceeds the proper value. In addition, when evaluating the long-term change in voltage of the distribution system is to simulate the tap operation of the distribution transformer.

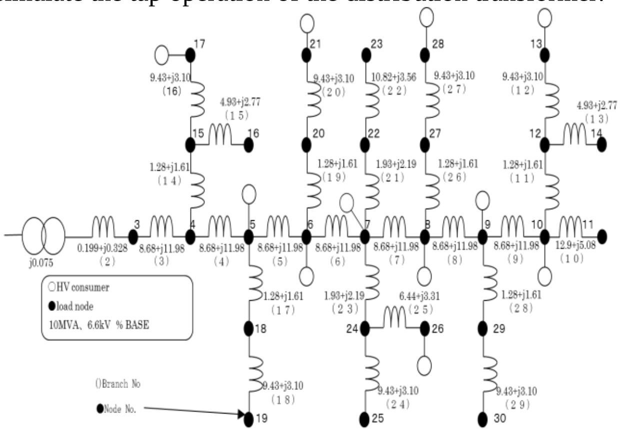

Fig.1 HV distribution system (1 feeder) model

A distribution system model on figure 1 has 11 HV consumers (o) and 28 load nodes (●). The demand pattern of the HV consumer is indicated on figure 2. A load node is composed of low-voltage (LV) distribution systems and customer load and PVs. In order to increase the reverse power flow, a total load per 1 feeder assumes the time of a light-load. Figure 3 is an example of the total load per 1 feeder of the Japanese electric distribution system. Reactive power has become supply reactive power due to the influence of HV customers. Load node uses only active power illustrated in figure 3 assuming the PF=1 and evenly divided active power at 28 locations.

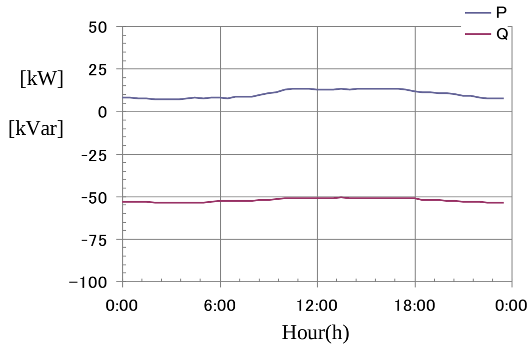

Fig.2. HV consumer's demand pattern

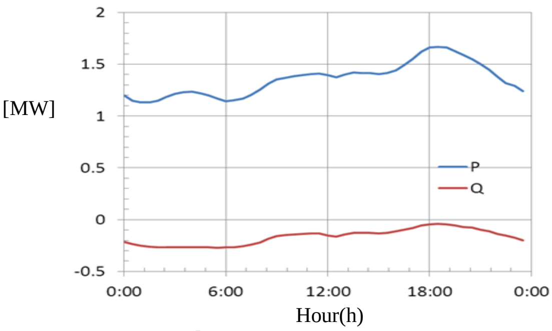

Fig.3. Load pattern of distribution system (1feeder, light-load)

LV distribution system model

The LV distribution system is connected to a load node on fig. 1. Pole transformer per feeder of the distribution system is 117 units, and the customer number per a pole transformer is 11. The total number of LV customer per feeder is 1287 (= 117 × 11). PV installation target to the LV customers of Japan is about 18% in 2020, is about 30% in 2030. In this study, set of 50% PV introduction rate of the LV customer to significantly compare the voltage control effect. The PV output per distribution system 1 feeder shown in Figure 4. Then the PV output is set to 28 equally divided in each load node.

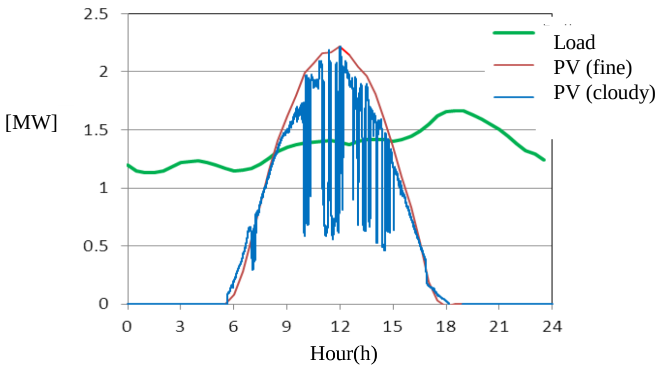

Fig.4. Load and PV output per feeder

Voltage regulators are not installed in the LV distribution system. Therefore, LV distribution system is not simulated in detail. However, the proper value of the distribution voltage is a 101 ± 6V of the LV distribution system. A simple LV distribution system model is connected to some of a load node (three points of No 3,6,13 in FIG. 1) and checked the excess of voltage appropriate value. A simple LV distribution system model is indicated on fig. 5. The LV distribution system model is composed of a pole transformer and low voltage distribution lines and customers. The customers are classified into two types on the presence or absence of PV installation.

LV distribution system shown in Fig. 5 simulates the equivalent circuit of Fig.6. Tap values of pole transformer of Fig. 6 refers to the voltage of the HV distribution system for each load node of the heavy load, and set the node 3 = 6600kV/105V, Node 6 = 6600kV/105V, the node 13 = 6450kV/105V. Consumer end voltage of the heavy load of the node 3,6,13 has become within the voltage proper value 101 ± 6V as shown in Fig.7.

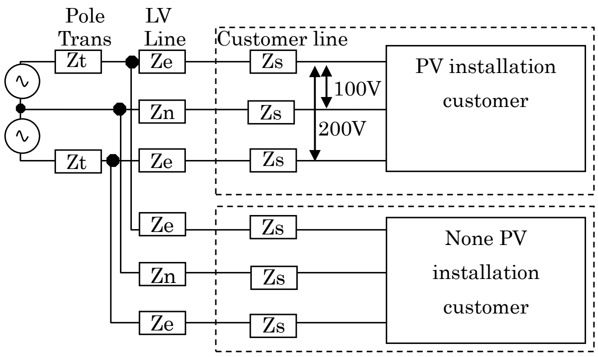

Fig.5 A simple LV distribution system model

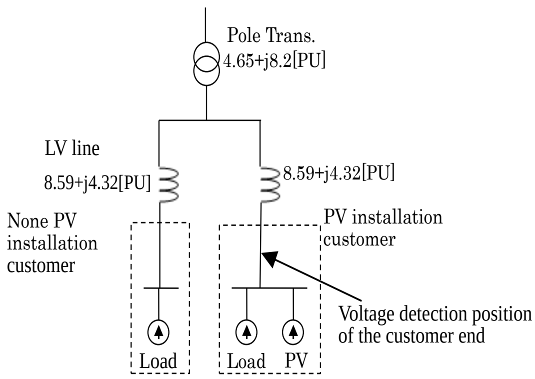

Fig.6 A equivalent LV distribution system model

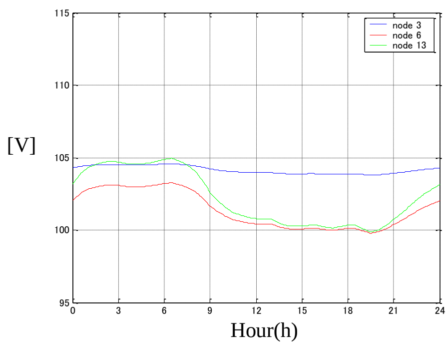

Figure 7 Consumer end voltage profile of the heavy load

Voltage regulators

Voltage regulators are set to 5 kinds, SVR, TVR, ShR, STATCOM and battery. The characteristic of the interconnection method and the control variable is shown in Table 1.

SVR is comprised of an autotransformer with load tap switching unit (LTC). Estimates the voltage drop of the control points by the magnitude of the load current, the secondary voltage by the tap control are ensured a certain range. The response time is 45-180 seconds of voltage control, in increments of voltage adjustment is from 1.25 to 2.5%.

Table 1 Classification of the voltage regulator

Control Variable / Installation	Discrete	Continuous
Series	SVR	TVR
Parallel	ShR	STATCOM, Battery

TVR is using thyristor to load tap switching circuit of the SVR. It can cope with high-speed voltage control and multi-frequency switching corresponding to the steep voltage fluctuation. Tap change is possible jumping tap change not only one tap change. The response time of the voltage control is equal to or less than 0.8s. An increment of voltage adjustment is 1.5%.
shR maintains the distribution voltage by off-on control of a shunt reactor.
STATCOM is controlled by continuously of about 50ms response the reactive power to supply from absorb by the inverter circuit.
Battery can charge and discharge of active power. And it can also be controlled reactive power continuously in 50ms response as STATCOM.
SVR and TVR and ShR are set dead zone and the operation time limit, respectively. Integrating the time of detected voltage exceeds the dead zone. When the integration time is greater than the operating time limit, run the operations of the tap change or ON/OFF change.
STACOM outputs a reactive power instantly so as to zero the difference between the target voltage and the detected voltage within the equipment capacity.
Storage battery controls the voltage by the output of reactive power as STATCOM. Also, active power outputs (charge and discharge) under the conditions of a constant ratio of active power and reactive power of the equipment capacity.

SIMULATION RESULTS

Under the analysis conditions described in the previous section, the voltage fluctuation of the distribution system with respect to the change of load and the PV output of days was evaluated by the continuous power flow calculation. Tap values of distribution transformers is 0.975, light load, PV output was verified in two patterns of the magnitude of the output fluctuation (Sunny and cloudy). Installation effect of voltage regulators is to assess the presence or absence of the proper value excess of the LV voltage.

Voltage change of the distribution system model

The voltage of the consumer end of the node No3,6,13 at the fine weather is shown in Figure 8. Consumer end voltage exceeds the proper value (101 ± 6V). Also exceed the proper value when cloudy. This model is to reproduce the voltage problems that occur when PV introduction of 53,000 MW in 2030 in Japan.

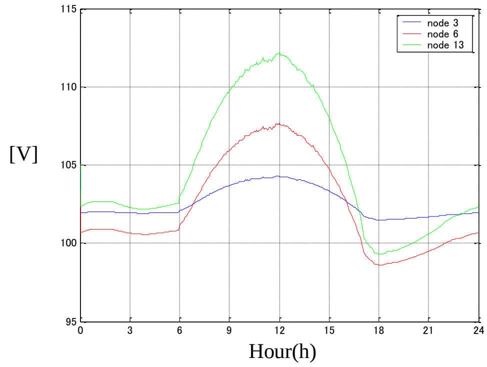

Figure 8 Voltage change of the day of the consumer end (fine weather)

Control effect of the voltage regulator

First, the voltage control effect in the case of installing one voltage regulator in the distribution system was analyzed Results shown in Table 2 (a), (b), (c). It should be noted that the ratio of the output of the active power and reactive power of the battery is 0.5: 0.87.

Table 2 (a) Case of STATCOM and battery

Case No.	Voltage regulator	Installed node	Capacity [kVA]	Weather	Maximum voltage of customer end [V]
1-1	Battery	6	740	Fine	108.4
1-2	Battery	11	460	Fine	106.8
1-3	Battery	11	460	Cloudy	106.8
1-4	STATCOM	6	840	Fine	108.4
1-5	STATCOM	11	575	Fine	106.6
1-6	STATCOM	11	575	Cloudy	106.6

Table 2 (b) Case of ShR

Case No.	ShR Maximum input [kVA]	Installed node	Maximum voltage of customer end [V]	Weather	ShR open close times/day
2-1	600	11	106.3	Fine	6
2-2	600	11	110.2	Cloudy	39

Table 2 (c) Case of SVR and TVR

Case No	Voltage regulator	Installed branch / Voltage detection node	Weather	Maximum voltage of customer end [V]	Tap switching times/day
3-1	SVR	4 / 6	Fine	108.4	8
3-2	SVR	4 / 10	Fine	107.2	11
3-3	SVR	6 / 8	Fine	107.4	9
3-4	SVR	6 / 10	Fine	107.4	11
3-5	TVR	4 / 10	Cloudy	110.7	38
3-6	TVR	4 / 10	Fine	107.2	–

Battery and STATCOM and ShR show high voltage control effect when placed at the end of the distribution system where voltage rise is large. Because battery can be controlled independently of active power and reactive power, and voltage control effect of reactive power, in a reverse power flow suppression by active power, less 10 to 20% equipment capacity in comparison to the STATCOM to control only the reactive power. Battery and STATCOM by its high-speed response eliminate the voltage deviation by the PV output fluctuation of cloudy weather. On the other hand, ShR, because control the amount of slow response in discrete, it can not be controlled within a proper value of the voltage due to the PV output fluctuation of cloudy weather.

SVR and TVR, it is the voltage control effect of the downstream system from the installation point, that it is not able to control a voltage to the appropriate value can be seen from the analysis results. Since the slow tap operation on integrated time the detection voltage exceeds the dead band set, that can not be compensated for voltage variations in the case PV output fluctuation is fast. However, SVR and TVR is installed in the system upstream, the voltage control effect becomes higher when estimating the system terminal voltage by LDC （Line Drop Compensator） Moreover, TVR is able reduce the voltage fluctuation in comparison to the SVR.

From these results, the installation location of the parallel installation device the end of the distribution system is desirable. Series installation device is installed to the system upstream, it is effective to voltage control by estimating the distribution system terminal voltage using LDC. STATCOM and the Battery can be compensated for fast and large voltage fluctuations.

Next, verify the voltage control effect by the combination of two voltage regulators. STATCOM and ShR of parallel installation device are installed in the node 11 of the downstream side of the distribution system. SVR and TVR of series installation device are installed in the branch 4 on the upstream side of the distribution system, to control the voltage to estimate the voltage of the node 10 on the downstream side. The analysis results are shown in Table 3.

Parallel installation device, there is a high voltage control effect when installed in the system downstream. Accordingly, it is possible to reduce the total device capacitance when the parallel device concentrates on distributed system terminal than dispersed. When combined parallel device and serial device, a fast voltage fluctuations suppressed in parallel device, in cooperative effect of compensating the overall voltage is controlled by series device, and greatly reduce the capacity of the parallel device. Although the case of STATCOM only required equipment capacity 525kVA, in the case of a combination with SVR reduce 50% capacity of STATCOM (200kVA), with TVR reduce 20% capacity of STATCOM (100kVA). It can be reduced total cost by combining a low-cost series device than STATCOM. On the other hand, when the combination of TVR and ShR, the voltage can not controlled within a proper value. The reason is because control of the two voltage regulators are both discrete. Also it can control the voltage within the proper value even when using two TVRs.

Table 3 combination of the voltage regulators results

Case No.	Voltage regulators		Maximum voltage of customer end [V]
4-1	SVR (Branch 4)	STATCOM 200kVAR	106.4
4-2	TVR (Branch 4)	STATCOM 100kVAR	106.4
4-3	TVR	ShR 35kVAR×2	107.6
4-4	TVR	ShR 35kVAR×3	107.6
4-5	SVR	SVR（Branch 7）	110.7
4-6	TVR	TVR（Branch 7）	106.1

From the these results, the distribution voltage control using multiple TVRs. Or it is considered that the combination of the parallel device capable of continuous control (STATCOM or battery) with the series equipment (TVR or SVR). Installation device should be selected by considering the use of the total cost and other applications.

CONCLUSION

Assuming the power distribution system of the Japanese residential areas, using a distribution system model that LV distribution voltage exceeds the proper value (101 ± 6V) in PV introduction rate of 30% or more, the installation location of the 5 kind voltage regulators and its voltage control effect of the combination were verified.

As a result, parallel installation voltage regulator is preferably installed in the terminal of the distribution system. Voltage regulator of the series installation is controlled by estimating the voltage of the system terminal installed in the distribution system upstream. And TVR and SVR and combining the parallel installation device of continuous control (STATCOM and battery) can be reduced 50 % or more of the parallel device capacity, it is confirmed that the cost reduction can be expected.

REFERENCES

[1] PRABHA KUNDUR, 1993, *Power system stability and control*, McGraw-Hill, 681-687.