Study Committee C6

Active distribution systems and distributed energy resources

Paper ID_10593

Development of Voltage and Power Flow Control Method for Distribution System using Distributed Energy Resources

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Background

- In Japan, large number of PV systems are installed in distribution systems and voltage fluctuation is a problem.
- To cope with the problem, voltage control devices such as step voltage regulators (SVRs) are used conventionally. Reactive power control of PV such as the constant power factor control is also used.

➢ Short to medium term

- In near future, further introduction of PV systems is expected. Therefore, these countermeasures should be improved.

➢ Medium to long term

- In future, many customers will have energy storage devices such as battery storage systems and EVs. Then, voltage and power flow fluctuations will become complicated.
- Therefore, advanced control methods to control voltage and power flow of the distribution systems are expected.

Objects of investigation

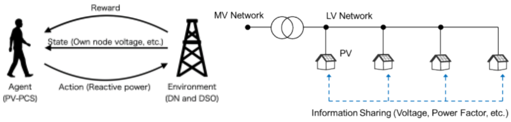
- The voltage and power flow control methods using distributed energy resources (DERs) are expected for future distribution systems.
- Therefore, control methods for short to medium term and control methods for medium to long term were investigated.

➢ Short to medium term

- Power factor control according to the amount of PV installed and the characteristics of the distribution line was investigated.

➢ Medium to long term

- Two control methods were proposed for medium to long term. One is the control method using reinforcement learning and the other is the control method through communication between customers.



(a) Control method using reinforcement learning

(b) Control method through communication between customers

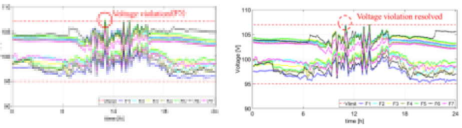
Figure 1-1: Control methods for medium to long term.

Simulation Analyses

- The simulation analyses showed that the proposed methods are effective for the voltage control of the distribution systems.
- The reactive power is controlled properly by the proposed methods.

➢ Short to medium term

- In future distribution systems, it is necessary to set the power factor according to the condition of the distribution line.
- Details are shown in **page 2**.



(a) Current practical power factor setting (90/95)

(b) Power factor setting optimal for each feeder

Figure 1-2: Example of Low-voltage Profiles on Heavy Load Sunny Day in 2040.

➢ Medium to long term

- Proposed two control methods are effective for the voltage control of the distribution systems.
- Simulation results show that reactive power from PV-PCS can be reduced by the proposed methods.
- Details are shown in **page 3**.

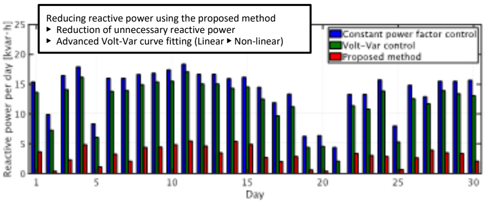


Figure 1-3: Reactive power per day of node 41-3 (control method using reinforcement learning).

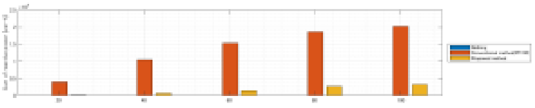


Figure 1-4: Reactive power per day of node 41-3 (control method through communication between customers).

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(continued)

Objectives of the Study

- It is necessary to maintain an appropriate voltage even when a large amount of PV is installed.
- The current power factor control in Japan is “constant power factor control”.

  The power factor is set in consideration of the resistance and impedance of the distribution line (High-voltage: HPF=90%, Low-voltage: LPF=95%).
- Challenges in current power factor control

  It is effective to control the power factor according to the amount of PV installed and the characteristics of the distribution line.

Simulation Conditions

- Modeling distribution lines in Japanese industrial and residential areas.

  The distribution line length is 5 to 10km, and the voltage is controlled by SVR.

  The number of High-voltage consumers is 89, and the number of LV consumers is 7,750.
- The year to be evaluated is determined in consideration of the load, and the amount of PV installed.
- There are 49 patterns for setting the power factor.

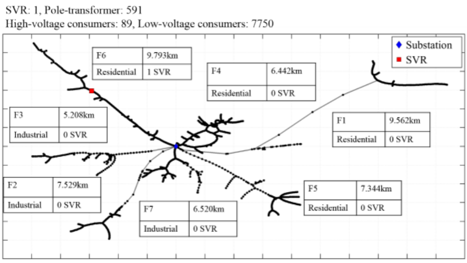


Figure 2-1 Distribution Network Model considering Actual Power System in Japan.

Table 2-1. List of Evaluation Conditions

Item	Settings
Evaluation year	2020, 2025, 2030, 2035, 2040
Date of assessment	4 days (Load: heavy/light load, PV: clear/cloudy days)
Endpoints	10 minute average low voltage power-receiving point voltage (6 o'clock to 18 o'clock)
PF setting value of the inverter	HPF: 85, 88, 90, 92, 95, 98, 100/ LPF: 85, 88, 90, 92, 95, 98, 100
Proper voltage range	95V-107V
LRT/SVR	LRT: Z properties, SVR: scalar LDC

Table 2-2. Amount of Load and PV Capacity

	2020	2025	2030	2035	2040
Total Load [kVA]	39,062	39,062	39,062	39,062	39,062
Total PV [kVA]	25,374	27,622	29,880	32,690	35,516

Experimental results & Discussion

- Table. III is a ranking table of combinations of High-voltage and Low-voltage power factors with little voltage deviation for the year to be evaluated. Gray hatching means that the voltage deviates from the proper voltage.
- The current power factor values are generally good for all years under consideration.
- The voltage of the distribution line would deviate from the proper value with the current power factor after 2030.

  ✓2030: The voltage is controlled to the proper value by optimizing the power factor of F4 and F5.

  ✓2035 and 2040: The voltage is controlled to the proper value by changing the connection phase of the transformer.
- The amount of voltage deviation is affected by the impedance (line length, wire type), load, and reverse power flow of each distribution line.

  → It is necessary to set the power factor and take measures according to the condition of the distribution line.

Table. 2-3 Voltage Evaluation for 49 Patterns of Power Factor

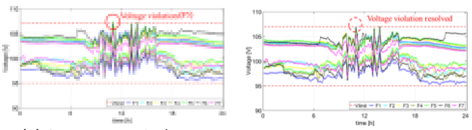
Rank	2020	2025	2030	2035	2040	Rank	2020	2025	2030	2035	2040
1	88/95	90/95	92/95	88/95	90/95	26	85/92	90/98	85/88	92/98	88/88
2	90/95	92/95	90/90	92/95	92/95	27	88/92	88/88	88/88	85/88	92/98
3	92/95	88/95	95/95	90/95	88/95	28	90/90	92/98	88/98	88/98	98/98
4	95/95	95/92	88/95	95/95	95/95	29	100/88	92/85	95/98	95/98	85/98
5	95/92	95/95	92/88	92/92	95/92	30	88/98	90/85	98/98	100/88	88/98
6	92/92	92/88	88/92	90/92	92/92	31	92/85	85/88	85/90	98/98	100/88
7	95/90	90/92	90/95	95/92	90/92	32	90/98	85/90	92/85	95/85	100/90
8	98/90	98/90	92/90	85/95	88/92	33	85/90	85/98	90/98	100/90	100/92
9	98/88	92/92	90/92	98/92	98/90	34	88/88	100/85	100/85	90/85	92/85
10	98/92	90/90	95/88	92/90	92/90	35	100/92	85/85	88/85	100/85	100/95
11	92/90	95/90	95/92	98/90	98/92	36	85/85	100/90	100/88	100/92	95/85
12	95/88	88/92	92/92	95/90	85/95	37	88/85	88/85	90/85	98/85	100/85
13	98/95	90/88	98/92	98/95	95/90	38	85/88	98/98	85/85	85/85	90/85
14	92/88	92/90	95/90	85/92	98/95	39	90/85	100/88	100/92	88/85	98/85
15	92/98	98/92	98/88	90/90	85/92	40	100/90	100/92	100/90	92/85	88/85
16	95/85	95/88	98/90	88/92	85/90	41	100/95	100/95	100/95	100/95	85/85
17	90/92	98/88	98/95	88/90	90/90	42	100/98	100/98	100/98	100/98	100/98
18	98/85	95/85	85/95	85/90	95/88	43	88/100	90/100	85/100	90/100	88/100
19	98/98	95/98	90/88	95/88	88/90	44	90/100	92/100	95/100	85/100	90/100
20	85/98	98/95	92/98	92/88	98/88	45	92/100	85/100	92/100	95/100	95/100
21	85/95	88/90	88/90	98/88	90/88	46	95/100	95/100	88/100	92/100	85/100
22	95/98	85/95	85/92	90/88	95/98	47	85/100	88/100	90/100	88/100	92/100
23	88/90	88/98	98/85	90/98	92/88	48	98/100	98/100	98/100	98/100	98/100
24	90/88	98/85	85/98	88/88	85/88	49	100/100	100/100	100/100	100/100	100/100
25	100/85	85/92	95/85	85/98	90/98						

- The voltage of F5 would deviate from the proper value in 2040 even if voltage maintenance measures are implemented.

  1. The power factor for PV is set individually for each distribution line.

  F1 is HPF 88%, F2 is HPF 90%, F3 is HPF 92%, F4 is HPF 100%, F5 is HPF 88%, F6 is HPF 88% and F7 is HPF 100%,

  2. The connection phase of the pole-transformer is changed in F5.



(a) Current practical power factor setting (90/95)

(b) Power factor setting optimal for each feeder

Figure 2-2 Example of Low-voltage Profiles on Heavy Load Sunny Day in 2040.

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continued

Q Control Method using RL

- The PV-PCS learns the appropriate reactive power using RL (Q learning in this study) to keep the voltage within a specified range.

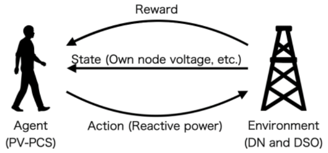


Figure 3-1: Schematic diagram of the proposed method using RL.

State: Voltage (206 to 216.6 [V] in 0.1 [V] increments)

Action: Power factor (0.85 to 1 in 0.01 increments)

$$\text{Reward: } r_{t+1} = \begin{cases} 10e^{(200(a_t-1))} & (s_t \le 213.5\ \text{V}) \\ -100 & (\text{otherwise}) \end{cases}$$

- we compared the following three methods:
  - I. Without reactive power control
  - II. Constant power factor control (=0.95)
  - III. Modified Volt-Var control
  - IV. Proposed method

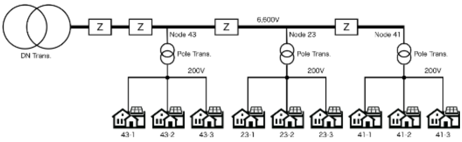


Figure 3-2: Middle voltage distribution network model.

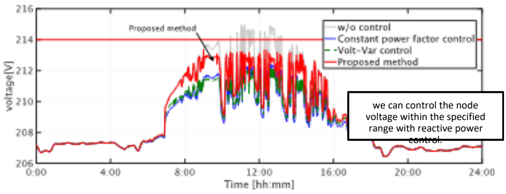


Figure 3-3: Voltage transition of node 41-3.

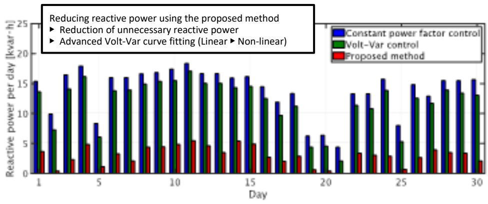


Figure 3-4: Reactive power per day of node 41-3.

Control Method through Communication between Customers

- The information of voltages and power factors is shared among customers, and the reactive power is controlled only when the voltage exceeds the limit.

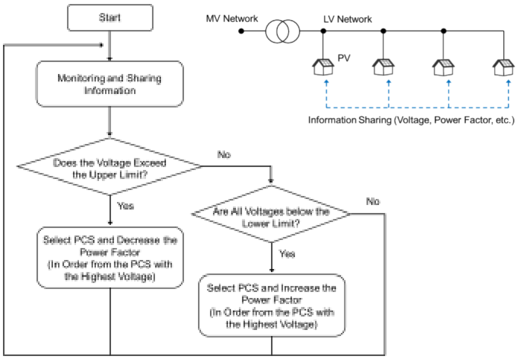
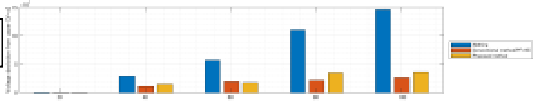


Figure 3-5: Control Method through communication between customers.

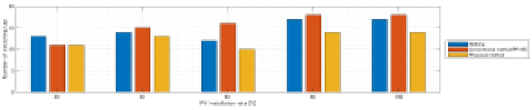
Simulation Study

- The proposed method was compared with the conventional method (constant power factor control: PF=0.95) using the PV output curve of the sunny day.
- Both methods are effective for the voltage regulation.
- Simulation results show that the proposed method is more effective because the amount of reactive power output and the number of operations of SVR are decreased.



(a) Voltage deviation amount.

(b) Reactive power output of PV systems.



(c) Number of switching (LRT and SVR).

Figure 3-6: Simulation results.