International Conference on Renewable Energies and Power Quality (ICREPQ'13)
Bilbao (Spain), 20th to 22th March, 2013
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, No.11, March 2013

Optimal Allocation and Planning of SVR on Distribution Network under Demand Growth

Ryo Watanabe[1], Yusuke Imanishi[1], Yusuke Hida[1], Yosuke Nakanishi[1], Ryuichi Yokoyama[1]

[1] Department of Environmental and Energy Engineering,Waseda University,
Shinjuku-ku, Tokyo, 169-0051 Japan,
Phone/Fax number:+81-3-5286-3126,
e-mail: q6-yw@asagi.waseda.jp, jike-yoshino@fuji.waseda.jp,
yusuke.h@akane.waseda.jp, yokoyama-ryuichi@waseda.jp

Abstract. Renewable energy resourses such as photovoltaic (PV) power and wind power have been installed in power networks as one of the countermeasures for global warming and depletion of fossil fuels. In particular, PV is the most promising of all renewable energy sources in Japan. However, the voltage may be risen due to the reverse power flow by connecting them to the distribution network. As one of the solutions for voltage problems due to the large scale penetration of PV generation, Voltage regulation by SVR (Step Voltage Regulator) has been expected. In this paper, we examine the optimal allocation and planning of the SVR for stabilizing voltages when PV generators are installed to a large extent into distribution networks. As a result, the voltage deviation can be reduced 84.5% on average with introducing a SVR. The optimal allocations are depended on capacities of PV generators. In addition, the voltage deviations are decreased 2.17% on average in every PV installation plan by replacement a SVR.

Key words

Photovoltaic generation, Locational allocation, Demand growth, Optimal facility planning

1. Introduction

In recent years, reduction of greenhouse gas emissions has been a serious issue through against global warming. Japanese government aims to reduce 25% of the emissions in 1990 by 2020. After the nuclear incident in Fukushima in Japan, the power sector have to take responsible for reducing 25% of the greenhouse emission by the expansion of the use of renewable energy more than ever. Among renewable energy sources, the PV is expected to play a key role in the expansion of renewable energy due to its simple introduction, and by 2020, PV is hoping to generate about 28GW, and 53GW by 2030. In particular, PV would be installed in residence area from the background of FIT(Feed-In Tariff). However, the voltage may be risen due to the reverse power flow by connecting them to the distribution network. In addition, the PV output changes have possibility to cause the voltage fluctuation. Up to the present, the studies on the optimal capacity and locational configuration of phase modifying equipment and voltage regulators aiming at voltage maintenance value (101±6,202±20V,etc）have been

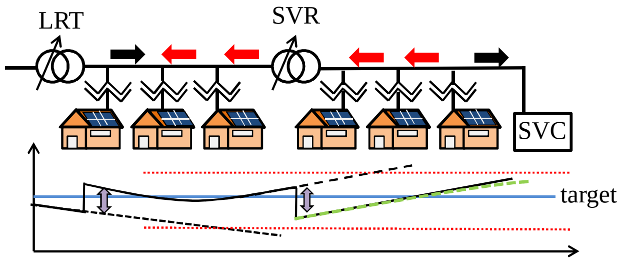

Fig.1 The outline of voltage operation with control equipment on distribution networks.

reported. Fig.1 shows the outline of voltage operation with control equipment on distribution networks. In Fig.1, the battery or SVC(Static Var Compensator) are able to suppress the surging voltage with the quick response speed. These devices have the disadvantages to adjust voltages since the capacity would be large. On the other hand, LRT (Load Ratio control Transformer) and SVR (Step Voltage Regulator) have the advantage to control the voltage with changing tap ratio. Especially, as one of the solution to the rising voltages due to the surplus energy of supplied power from PV, applying SVR has been considered. The optimal allocation and operation methods of SVR have been reported in the past[1-5]. However, it is thought that the load such as demand and PV generators would be further introduced in distribution network from now on. There are few reports of the optimal arrangement and the advantage of a SVR installation considering the LDC (Load Drop Compensation) control of LRT.

In this paper, we propose the optimal allocation of SVR in distribution networks to stabilize voltages when installation of PV generators is increased. Furthermore, planning and evaluation approaches of SVR are presented in case of large scale installation of PV generation.

2. Structure and operational condition of test network

2.1 Structure of Test model

In this study, we decide the allocation and replace SVRs in a distribution network. The structure of the test distribution is shown in Fig.2.

Features of the distribution network are as follows;
-All nodes are P-Q specified nodes.
-The distances of each branch are 0.3km.
- The based capacity of the network is 4MVA and the slack node is set to the primary bus on a distribution substation (branch1).
-The resistance is 0.062Ω and the reactance is 0.072Ω in every branch.

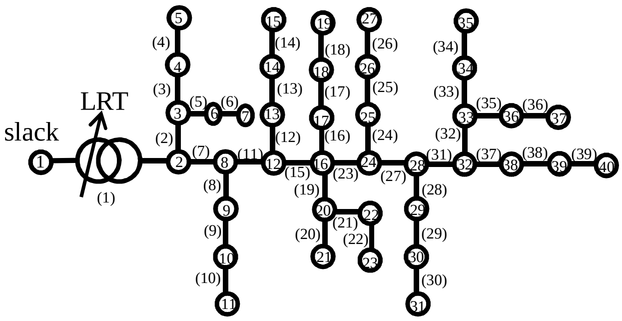

Fig.2 40bus distribution network model.

2.2 Daily Profile of Demand

A day with off-peak demand is used in simulations. Daily demand data is measured every hour at a site in Saitama prefecture, Japan. The off-peak demand was observed to 2009/4/26. The active and reactive power is calculated on condition that the power factor is 0.9. The demand curves are shown in Fig.3.

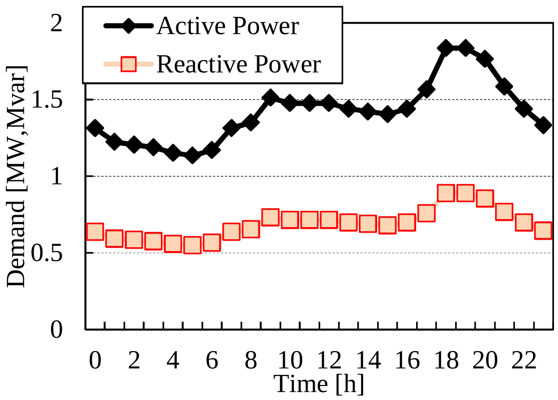

Fig.3 Daily Profile of Demand.

2.3 Daily profile of PV output

The PV output data on a sunny day is used to conduct simulation and analysis. The PV output on the sunny day is actual data measured in Tokyo area. The normalized PV power is shown in Fig.4.

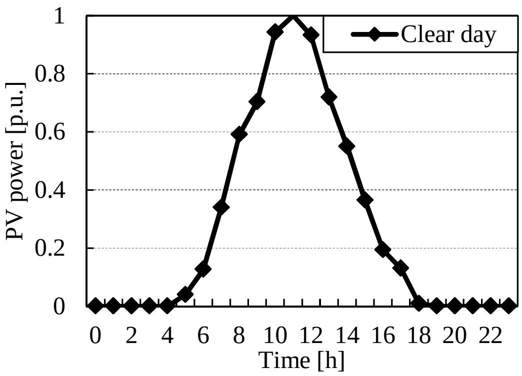

Fig.4 Normalized PV power profile on a sunny day.

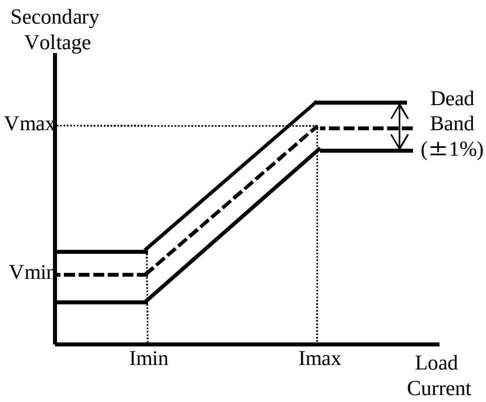

Fig.5 The logic of LDC control.

3. Components of distribution network and formulation of control mode

3.1 Control of LRT by using LDC

Most of the load ratio control transformers (LRT) are controlled to adjust voltage in the network by a line drop compensator (LDC). Absolute values of current and voltage on the secondary side are measured and transfer tap ratios of LRT are regulated based on those measured values. The logic of control modes is shown in Fig. 5. V_{MAX}, V_{MIN}, I_{MIN} and I_{MAX} are decided by the number of customers in the network and the total amount of demand. They show the zigzag curves which has a dead zone. The tap in LRT is changed to maintain the secondary voltage within this dead bound. The number of taps is 17, and V_{MAX}=6800V, V_{MIN}=6400V, $I_{MIN=}$40A I_{MAX}=240A in this network. The dead bound is ±1% of voltage base in Fig. aa. The secondary voltage can be controlled from 6000V to 7200V by changing tap and its step size is 0.075V. The transformer ratio of LRT and secondary voltage can be expressed as follows.

$$N_{LRT} = 7.2 - S_{LRT} \cdot (17 - Tap_{LRT}) \quad \cdots(1)$$
$$V_{2,LRT} = N_{LRT} \cdot V_{1,LRT} \quad \cdots(2)$$

where,
N_{LRT} : Transformer ratio of LRT, S_{LRT} : Step size of the LRT ratio, Tap_{LRT} : LRT tap position, $V_{1,LRT}$, $V_{2,LRT}$: Primary, Secondary voltage of LRT

3.2 SVR model

The voltage regulation is carried out with switching the tap of SVR (Step Voltage Regulation). The sudden voltage sag is not regulated only by changing the tap of SVR. However, SVR isusually installed in distribution networks since it is low cost and esay to introduce. In installing SVRs, it is also necessary to take the tap position and ist control into consideration.

$$N_{SVR} = 6.6 \cdot (95 + S_{SVR} \cdot (Tap_{SVR} - 1))/100 \cdots(3)$$
$$V_{2,SVR} = N_{SVR} \cdot V_{1,SVR} \quad \cdots(4)$$

where,
N_{SVR} : Transformer ratio of SVR, S_{SVR}:Step size of the SVR ratio, Tap_{SVR} : LRT tap position, $V_{1,SVR}$, $V_{2,SVR}$: Primary, Secondary voltage of SVR

Table1. The relationship of tap ratio and tap position.

Tap position	1	2	3	4	5	6	7	8	9
Tap ratio	95	96.25	97.5	98.75	100	101.25	102.5	103.75	105

Transformer ratios of SVR and secondary voltage can be expressed as equation (3) and (4). In this study, the SVR is assumed to have nine taps and its step size is 1.25%.The relationship of tap ratios and tap position is described in table.1[4].

4. Allocation of SVR for voltage regulation

4.1 Increase of PV generators

In this paper, the optimal allocation of SVR is carried out to maintain the voltage stability when the installed capacity of PV generators is increased. In the test model, areas in the frame in the Fig.6 is asuumed to consisit of commercial districts or industrial districts. The others area is asuemmed to consisit of residential districts.

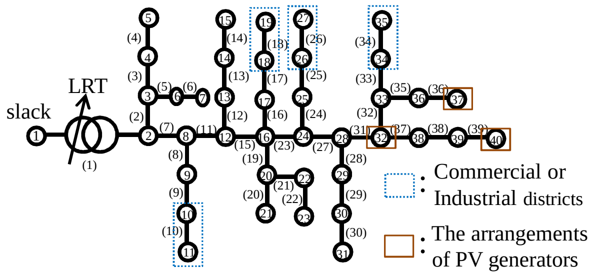

Fig.6 The constitute of the network model.

PV generators are assumed to be equally installed at the end of network bus 32, 37 and 40 PV generators are installed according to three plans of Fig.7. In each plan, the insatalled capacity of PV generators is increased and accumulated gradually at ten different sections from 3.75% to 37.5% of system capacity. In addition, the power factor of PVs is set to be 1.0 and the output of PVs is known.

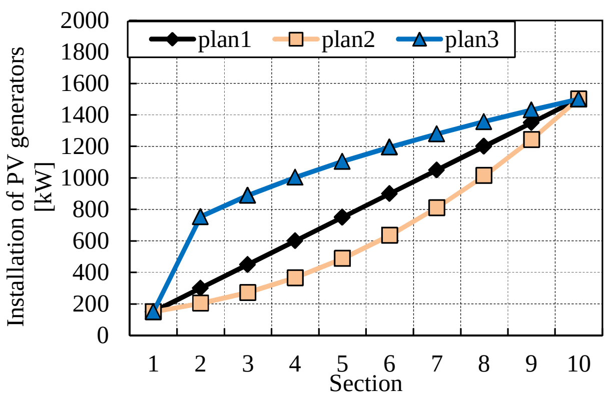

Fig7. PV installation plans.

4.2 Objective Function of SVR allocation

In this study, optimum SVRs are allocated to keep voltage within a disireble range by taking LDC control of LRT into consideration. An objective function for SVR allocation is configured as in equation (5) .

[Objective function for SVR Allocation]

Minimization of the voltage deviation

$$f = \min \sum_{t}^{T} \sum_{i}^{M} (V_{it} - V_{ref})^2 \qquad \cdots(5)$$

Where,

f : Objective function, M : Number of Nodes, T : Number of time cross section to consider, V_{it} : Node i, the voltage section t, V_{ref} : Voltage reference value (6600V)

4.3 Constraints of SVR allocation

When SVRs are allocated, the power flow and the voltage limits and tap bounds of LRT and SVR are set as constraints. Constraints are shown in below. In this study, the Newton- Raphson method is utilized to obtain each bus voltage and the line flow constraint.

[Constraints]

ⅰ) Power flow constraint

$$\boldsymbol{I}=\boldsymbol{YV} \qquad (6)$$

ⅱ) Voltage upper and lower limit

$$V_{lower} \leqq V_i \leqq V_{upper} \qquad (7)$$

ⅲ) SVR tap bounds

$$SVR_{tap,min} \leqq SVR_{tap} \leqq SVR_{tap,max} \qquad (8)$$

ⅳ) LRT tap bounds

$$LRT_{tap,min} \leqq LRT_{tap} \leqq LRT_{tap,max} \qquad (9)$$

Where,

$\boldsymbol{I}$、$\boldsymbol{V}$: Current and Volatage in each bus, $\boldsymbol{Y}$: admittance matrix, V_{min} : Voltage lower limit（6300V）, Vmax : Voltage upper limit（6900V）, $SVR_{tap,min}$, $SVR_{tap,max}$: SVR tap bounds, SVR_{tap} : SVR tap position, $LRT_{tap,min}$, $LRT_{tap,max}$: LRT tap bounds, LRT_{tap} : LRT tap position

SVRs are allocated by solving the above optimal power flow calculation with constraints equations (6)-(9).

5. Application to A Test Network

5.1 Decesion a SVR allocation in PV pattern1

First, we decide to allocate a single SVR to 10 cadiadte sections in distribution feeders under PV insatallation plan-1. The voltage deviations and the placements of a SVR are shown in Fig.8. In Fig.8, the deviation can be reduced 84.5% on average by introducing a SVR. The results of the simulation is summarized to below.

(1) After the SVR allocation to section 2, the optimal installation site changes. This is because the voltage drop is improved, since PV generators are introduced and power flow on line is decreased.

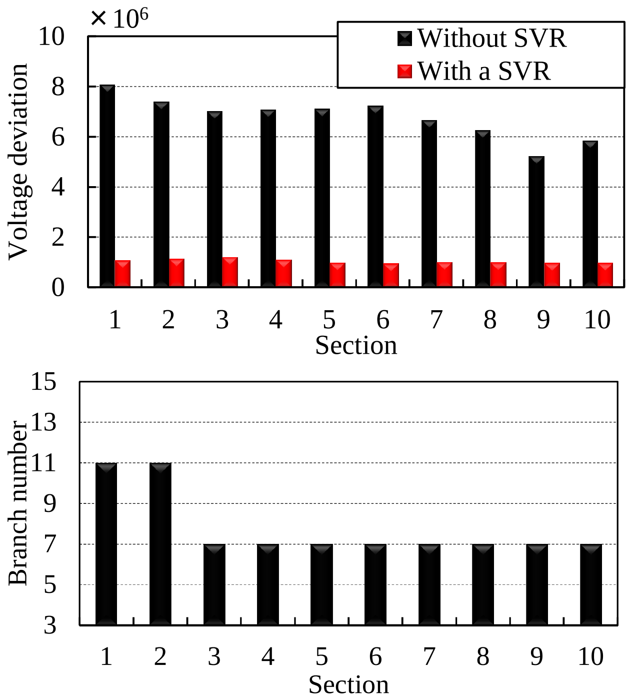

Fig.8 The voltage deviations and the allocations of a SVR in PV plan1.

(2) The voltage deviations increased in some years without SVR by setting lower sending voltage caused by LDC control.

(3) The tap position of SVR is stepped down due to the reverse flow at the section 10.

5.2 Comparison of the optimal allocation of a SVR in different PV patterns

Fig.10 shows voltage deviations and the allocation of a SVR. The voltage deviation can be reduced drastically by introducing a SVR in each PV pattern.

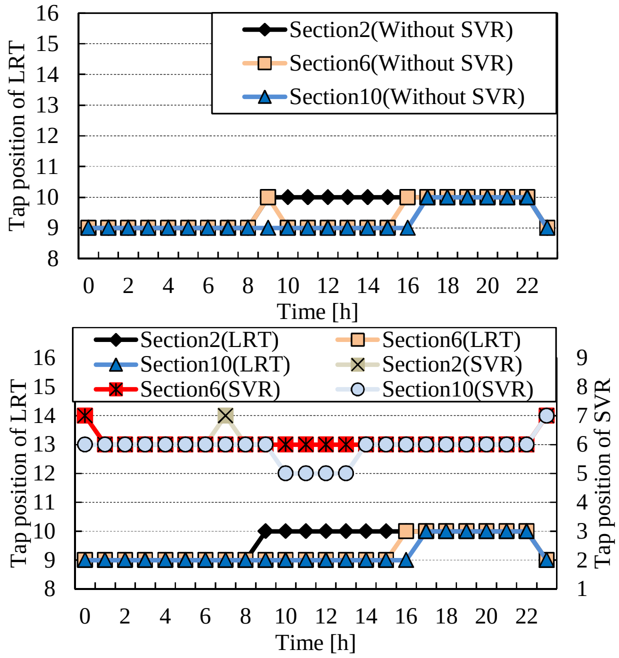

Fig.9 The tap position of LRT and SVR.

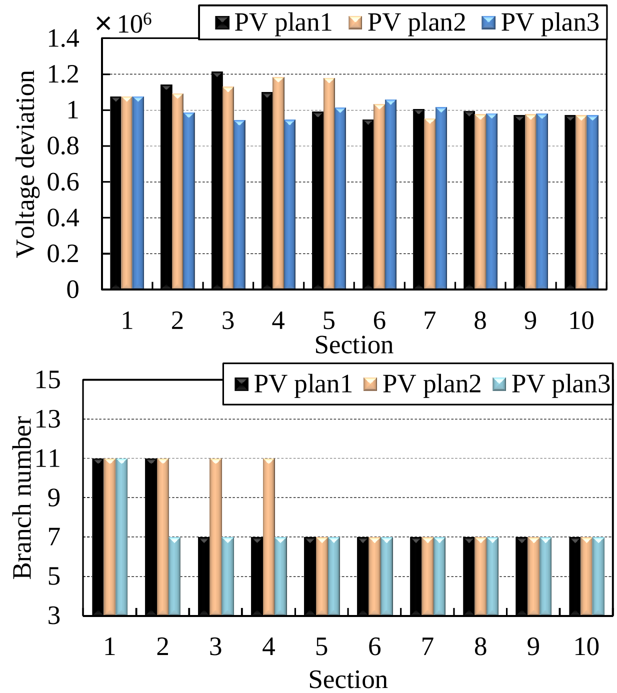

Fig.10 The comparison of the voltage deviations and the allocations of a SVR in each PV plan

The deflections of each pattern are different due to the position of LDC when the section is 2-5. Even though the width of voltage drop is even lower, the deviation is increased because the sending voltage is set to high at PV pattern 1 and 2. In pattern 3, on the other hand, the deflection is gained when the voltage is increased due to the reverse flow at the section of 6.

5.3 The optimal replacement of SVR

Since the optimal allocation depends on capacities of PV generators, SVR allocation and installation plans are determined to minimize the total cost of insatallation in several sections. We defined the costs of allocation as follows. The count of initial cost is 3 points, and the displaced cost are 2 and the operational cost is 1. Then, we calculated the cost and sum of voltage deviation.

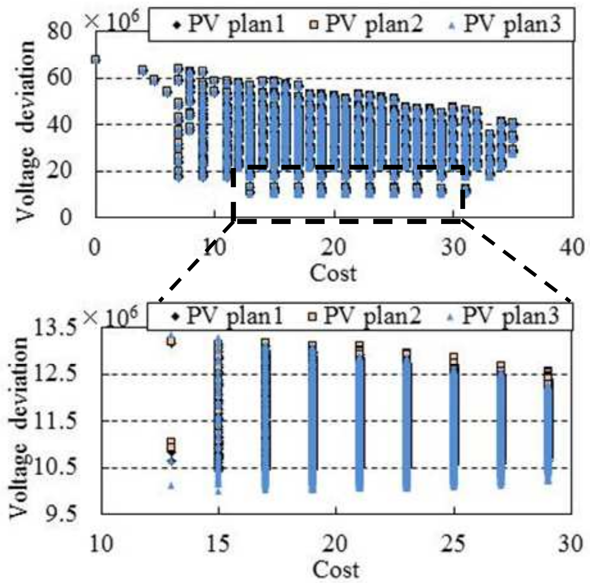

Fig.11 The relationship of the cost and the deviations until the 10 section

The relationship of the cost and the deviations until the 10 section is shown in Fig.11. Fig.11shows the voltage deviations are decreased if more cost are paid. The sum of the voltage deviation is the smallest in PV pattern3. In addition, the voltage deviations are reduced 2.17% in PV plan1, 3.02% in plan2, 1.32% in plan3 by displacing a SVR.

6. Conclusion

We proposed an approach to allocate SVR in distribution feeders in case of large scale insatallation of PV genrators in this paper. As the first step, the LRT model using LDC control and the SVR model is formulated. As the second step, the arrangement of aSVR is determined by solving the optimal power flow calculation utilizing enumerative method. The voltage deviation can be reduced to 84.5% in average with introducing a SVR. Conducted simulations shows that the optimal allocation is depending on capacities of PV insatlled generators. Finally, The optimal replacement of SVR is conducted. The voltage deviations are reduced 2.17% in PV plan1, 3.02% in plan2, 1.32% in plan3 by displacing a SVR. As a future subject, the cooperative control with SVC are to conduct considering the intermittency of PV generators.

References

[1] T. Kobayashi and H. Aoki, "SVR Optimal Placement Problem in Distribution Network with Distributed Generators", Power and Energy Society General Meeting, 2012 IEEE.

[2] J. Sugimoto, R. Yokoyama, T. Niimura, and Y. Fukuyama, "Tabu search based-optimal allocation of voltage control devices by connections of distributed generators in distribution systems", Universities Power Engineering Conference,2004. UPEC 2004.39th.

[3] J. Sugimoto, R. Yokoyama, Y. Fukuyama, V.V.R, Silva and H. Sasaki, "Coordinated allocation and control of voltage regulators based on reactive tabu search", Power Tech, 2005 IEEE Russia.

[4] J. Sugimoto, R. Yokoyama, G. Fujita, and Y. Fukuyama, "Cooperative Allocation of SVR and SVC for Voltage Fluctuation in Case of Connecting Distributed Generators", IEEJ Trans. PE, Vol.126, No.12, pp.1191-1198(2006).

[5] H. Mori and T, Yoshida, "Multi-Objective Optimal Allocation of SVRs in Distribution Networks", Intelligent System Applications to Power Systems, 2009.

[6] K. Koeda, Y. Zoka, T. Ueyama, Y. Naoto and H. Sasaki, "A Study on a New Distribution System Planning with Considering Distributed Generators Installation", IEEJ Trans. PE, Vol.126, No.8, pp.789-797(2006)

[7] T. Senjyu, Y. Miyazato, A. Yona, N. Urasaki and T. Funabashi, "Optimal Distrubution Volatage Control and Coordinate With Distributed Generation", Power Delivery, IEEE Transactions, pp.1236-1242(2008)

[8] T. Senjyu, Y. Miyazato, S.Toma, A. Yona, N. Urasaki, T. Funabashi and Chul-Hwan Kim, "Optimal Control of distribution voltage profile by considering the number of operation of the distribution installations", Power and Energy Society General Meeting-Conversion and Delivery of Elevtrical Energy in the 21st Century, 2008 IEEE.

[9] S.Toma, T. Senjyu, Y. Miyazato, A. Yona, K.Tanaka and Chul-Hwan Kim, "Decentralized voltage control in distribution system suing neural network", PEcon2008, IEEE 2nd International.

7. Biography

Ryo Watanabe was born in kanagawa, Japan, on November 7, 1988. He received B.S degree in electrical engineering from Waseda University, Tokyo, Japan, in 2011. He is now a graduate student at the Graduate School of Environment and Energy Engineering in Waseda University in Japan. His research interest is PV generation's impact assessment on power systems.

Yusuke Imanishi was born in Kochi, Japan, on May 16, 1989. He received B.S. degree in electrical engineering from Waseda University, Tokyo, Japan, in 2012. He is now a graduate student at the Graduate School of Environment and Energy Engineering in Waseda University in Japan. His research interest is the short period forecasting PV output using Hemispherical Photograph.

Yusuke Hida was born in Kagoshima, Japan, on February 9, 1986. He graduated from department of electrical engineering in Meisei University, Tokyo Japan, in 2008. He received the degree of M.S in environment and energy engineering from Waseda University in 2010. He is now Ph.D student at the graduate school of environment and energy engineering in Waseda University in Japan. His research interests are environmental issues of power systems.

Ryuichi Yokoyama received the degrees of B.S., M.S. and Ph.D. in electrical engineering from Waseda University, Tokyo Japan, in 1968, 1970 and 1973, respectively. After being engaged in Mitsubishi Research Institute, from 1978 through 2006, he worked in the Faculty of Technology of Tokyo Metropolitan University, and since 2007, he has been a professor at the Graduate School of Environment and Energy Engineering in Waseda University, Japan. Prof. Yokoyama is a fellow of IEEE of USA and the IEE of Japan and members of SICE of Japan, CIGRE, etc.