The Introduction of Base Power Supply used Surplus Electric Power from Photovoltaic System

TOSHIFUMI YUJI[1*], CHE XIAOXUAN[2], TOSHIO BOUNO[3], NORITSUGU KAMATA[4]
[1]Faculty of Education, University of Miyazaki, Miyazaki, JAPAN
[2]Faculty of Engineering, Wuhan University, Wuhan, CHINA
[3]Department of Electrical and Electronic Engineering, National Institute of Technology, Sasebo College, Nagasaki, JAPAN
[4]Faculty of Industrial Education and Technology, King Mongkut's University of Technology Thonburi, Bangkok, THAILAND.
*Email: yuji@cc.miyazaki-u.ac.jp

Abstract: - The interconnection of large quantities of the distributed power source, such as PV power source, to the power electric system is anticipated, and as a result, the fluctuations of voltage and frequency will increase and make the adjustment of the demand and power supply balance difficult. The present paper describes new method of the large-scale PV System used Pumped Storage System (PSS) to store the electric power from large-scale PV system in the daytime and power supply in the nighttime as base power supply. Large-scale PV system with PSS is studied by computer simulation. The contents include the installed position of PSS, the capacity of PSS, capacity of transmission line, power generation cost, and base power supply. It will be possible to use base power supply from large-scale photovoltaic power instead of electric power from nuclear or thermal power station, satisfy demand and reduce or stop the output of nuclear station or thermal power station, use the surplus electric power, maintain a stable power supply, energy-saving, and a suitable adjustment of the power demanded-supply balance.

Key-Words: - Large-scale PV System, Pumped storage system, Base power supply, Installed position of PSS, METPV-3 data

1 Introduction

At present, PV system [1-4] is being installed in deserts and places that far from the areas of demand. It is necessary to use PSS to solve following major problems. Although the electric power from PV system supplied to load directly, it remains large amounts of surplus electric power. In addition, if the large amounts of surplus electric power flow backward to the electric power system, it would have a great influence on a quality of the electric power system because of the voltage and frequency changing in electric power system.

The interconnection of large quantities of the distributed power source, such as PV power source, to the power electric system is anticipated, and as a result, The fluctuations of voltage and frequency will increase and make the adjustment of the demand and power supply balance difficult. By applying PV system with PSS [5] to the large-scale PV system in order to energy-saving, a stable energy supply, and the widespread use of renewable energy is expected. The large-scale PV system with PSS is composed of PV system, PSS, DC load as well as DC transmission line. PSS is used to transform the surplus electric power from large-scale PV system in the daytime into water energy by pump and transform water energy into electric power in the nighttime as base power supply by generation.

In this paper, a new method of electric storage for the large-scale PV System is proposed. The PSS is composed, the data of solar irradiance and temperature and four different types of the residential load patterns are used to calculate by simulating method. The electric power of PV system, surplus electric power, installed position of PSS, the capacity of PSS, the capacity of transmission line, power generation cost, and base power supply are analyzed.

The results indicate the base power supply has an output ability of 1,511 kW or 1,419 kW, which can be seen as 15.11 % or 14.19 % of the capacity of the large-scale PV system (10MW). The results indicate that it is possible to use PSS for store surplus electric power and base power supply in the large-scale PV system. It is possible to PSS will be used as energy storage system in large-scale PV system or renewable energy system as base power supply in the future.

2 New Proposal

Generally, PSS is used as to store the surplus electric power of such as, nuclear power plant, thermal power station in the nighttime. On the other hand, it discharges electric power at the peak demand in the daytime. We propose opposite method for PSS to store the electric power from PV system [6] in the daytime and discharge in the nighttime for the usage of the base power supply, due to the fact that large-scale PV system is usually installed in small towns or cities in order to generate the large amounts of the surplus electric power in the daytime. It is reasonable to cut down or stop producing the surplus electric power from nuclear power plant or thermal power station in the nighttime because it can be stored by PSS and used in the nighttime.

Fig.1 shows the large-scale PV system with PSS. The system is composed of PV system, PSS, DC load as well as DC transmission line. The large-scale PV system is assumed to set up in Aomori prefecture in the north of Japan. At the same time, the load is set up in Tokyo. The distance between PV side and load side is about 500 km. PSS is installed at PV, load or middle side respectively. The DC electric power from PV system supplies for DC load [7][8] directly. When the surplus electric power occurs, it would be stored by PSS. Alternatively, when the electric power from PV system lack for load, the load would be supplied electric power by PSS.

In this study, the capacity of the large-scale PV system is 10 MW. The residential houses are100, and public facilities have two elementary schools, two junior high schools, one city hall and one company. Initial storage value is 150 MW. PSS possesses a total storage efficiency of 71 % [9][10].

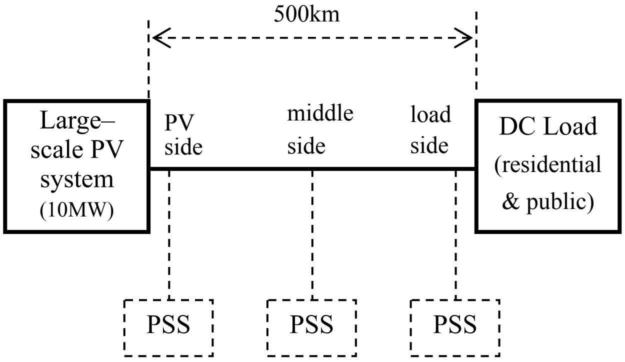

Fig.1: PV system with PSS.

3 Simulation Method

The simulation is employed following calculations [11-14]: the electric power of large-scale PV system and the loss of transmission line, while, apply to four types of residential load patterns and the public facilities load of two elementary schools, two junior high schools, one city hall and one company. The simulation is calculated continuously every hour for a year [15]. The data gained from the simulation are resources for making a decision of installed position of PSS, the capacity of PSS, the capacity of transmission line, power generation cost, and base power supply in detail.

3.1 The Electric Power of PV System

METPV-3 data from NEDO of Japan (solar irradiance and temperature) [16] is used to calculate the electric power of PV system. The solar irradiance is assumed equal for all places installed PV panels.

The polycrystalline silicon module is employed, the conversion efficiency of module is 14 % at the cell temperature 25 °C, and intensity of solar radiation is 1.0 kW/m^2. The electric power of PV system P_0 is calculated by equation (1) a year.

$$P_0 = \sum_{i=0}^{8760} S\Phi(i)\frac{\eta(i)}{100}\left[1 - 0.005\left(T + \Delta T(i)\right)25 -\right]\Delta t \quad (1)$$

Where S is the area of PV panels, Φ(i) is intensity of solar radiation on slope (tilt angle is 35 °and installed toward south), η(i) is conversion efficiency of PV module, T is module temperature, ΔT is range of temperature and Δt is time interval.

3.2 Residential Load Patterns

In order to study relationship between electric storage and different types of the residential load patterns, there are four different types of the residential load patterns [4] are used. These patterns are considered separately with three different seasons: summer, winter and autumn [17]. The residential load patterns in winter is shown in Fig.2. The load change of the pattern Home 1 is low from10:00 to 16:00. The pattern Home 2 shows big load change at midnight, morning and evening. The pattern Home 3 shows is low in the morning, but it is big at evening. The load change of pattern Home 4 is slow all day.

3.3 Public Facilities Load Patterns

The public facilities load set as two elementary schools, two junior high schools, a city hall and a company, as shown in Fig.3.

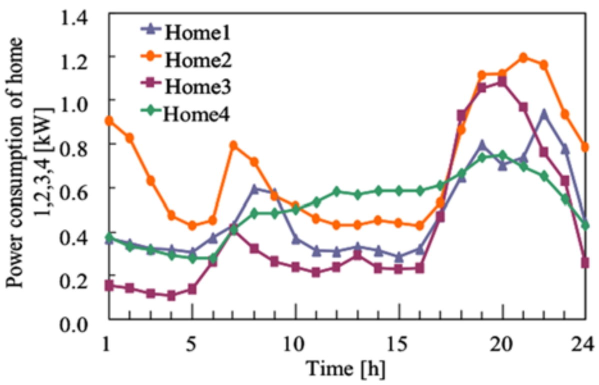

Fig.2: Residential load patterns (Winter).

3.4 Loss of Transmission Line

The loss of transmission line P_L is calculated by equation (2).

$$P_L = 2I^2Rl \tag{2}$$

Where I is load current, R is resistance of one line and l is distance. The distance between PV side and load side is assumed to be about 500 km, the distance between PV side and middle side is about 250 km.

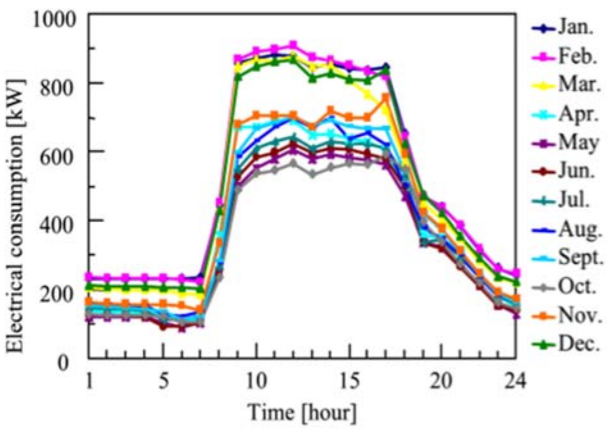

Fig.3: Public facilities load patterns (winter).

4 Results and Discussions

The large-scale PV system with PSS is studied by computer simulation. The contents include the installed position of PSS, the capacity of PSS, capacity of transmission line, power generation cost, and base power supply (base load power).

4.1 The Surplus Electric Power

Fig.4 shows the DC electric power from PV system (PV power), load power consumption, the surplus electric power, and rate of surplus electric power to PV power. As we can see, after PV power is supplied to load directly, there are large amounts of the surplus electric power. It is noticeable that there is necessity to store the electric power from PV system in the daytime.

The surplus electric power has differences depending on where PSS is set up at PV, middle and load side, as shown in Fig.5. The rate of the surplus electric power at middle side to PV side is 89.6 %- 92.4 %, and load side to PV side is 79.3 %- 84.8 %, respectively.

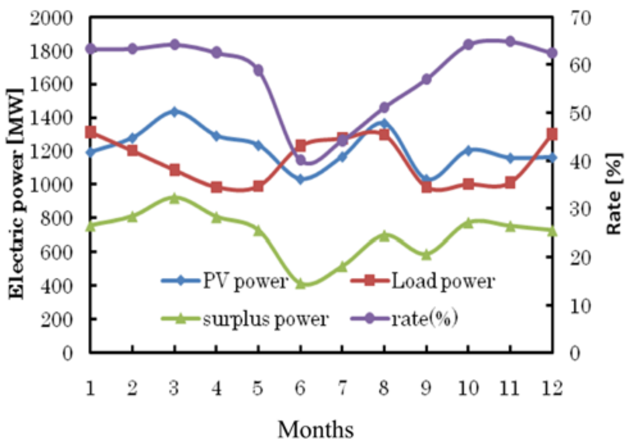

Fig.4: The surplus electric power.

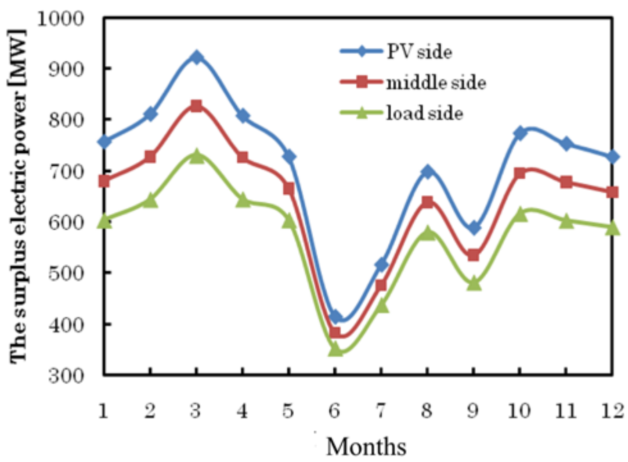

Fig.5: The surplus electric power at three sides.

4.2 The Capacity of PSS and Transmission Line

As we have noticed that there are large amounts of the surplus electric power from Fig.5, it is worth to look at Fig.6 which illustrates the capacity of PSS. The capacity rate of PSS at middle side (side 2) is 9.5% lower and load side (side 3) is 19% lower than that of PV side (side 1) due to the power loss by distance of the transmission line. It is obvious that the capacity of PSS depends on installed position of PSS and the capacity of PSS can be reduced, if PSS is set up at middle side or load side. The storage capacity of PSS is equal to the maximum surplus electric power within a year.

The capacity of transmission line is closely related to where the PSS is installed. When PSS is set up at PV side, the capacity of transmission line is equal to the maximum load power consumption. In the contrast, if it is at middle side or load side, the capacity of transmission line is determined by the maximum value of surplus electric power and load power consumption.

Fig.7 explains the capacity of transmission line. The capacity rate of transmission line at middle side and load side is approximately three times higher than that of PV side. The PSS should install at PV side so that the capacity of transmission line and the cost can be reduced. In addition, if PSS has already constructed at PV, middle or load side, it can be directly and initial investment can be reduced.

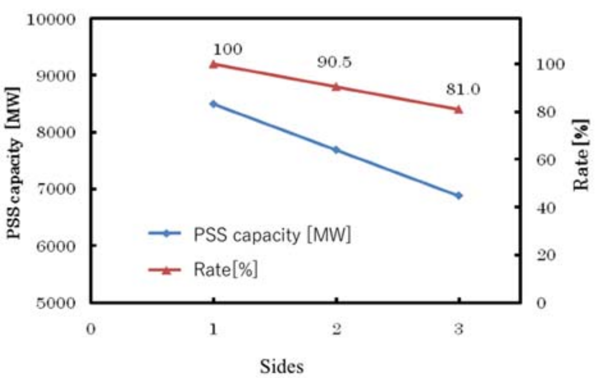

Fig.6: The capacity of PSS.

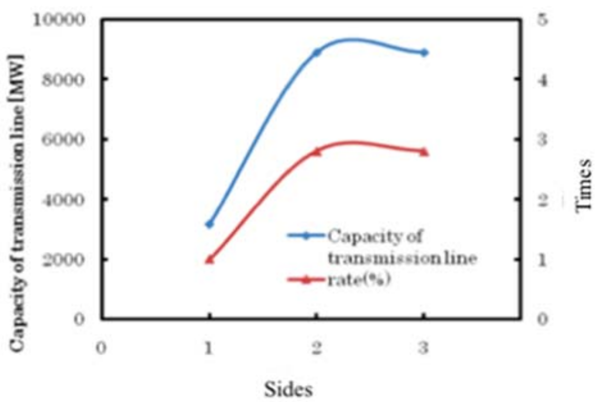

Fig.7: The capacity of transmission line.

The land and personnel cost between Tokyo and Aomori prefecture are follows: the land cost in Tokyo is approximately 23.7 times higher than Aomori which is 669,500 JPY/m^2 and 28,300 JPY/m^2 respectively. The personnel cost in Tokyo is 372,900 JPY/month, and in Aomori is 222,200 JPY/month. The personnel cost in Tokyo is 1.7 times higher than Aomori. PSS should install in Aomori to reduce the land and personnel cost.

4.3 Base Power Supply

It is proposed a new method for PSS to store the electric power from PV system in the daytime and discharge in the nighttime as base power supply [4]. Type1 demonstrates that the surplus electric power is not directly supplied to loads but it is used as base power supply to reduce or stop the output of nuclear or thermal power station. PSS (capacity: 1,511 kW) can supply base electric power to load. (See Fig.8). According to Fig.9, Type 2 demonstrates that the surplus electric power is directly supplied to load. If there is still surplus electric power, it is used as base power supply. PSS (capacity: 1,419 kW) can supply base electric power to load.

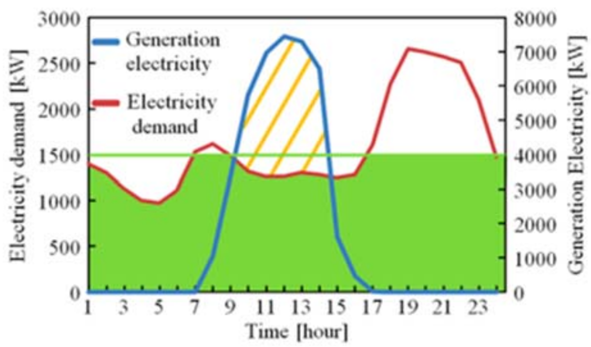

Fig.8: The base power supply of Type1 (1st / January).

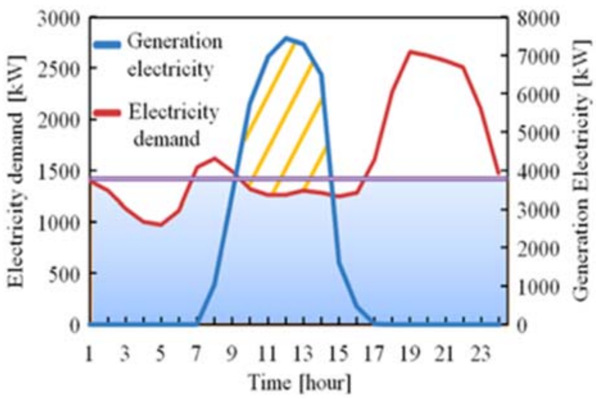

Fig.9: The base power supply of type2 (1st / January).

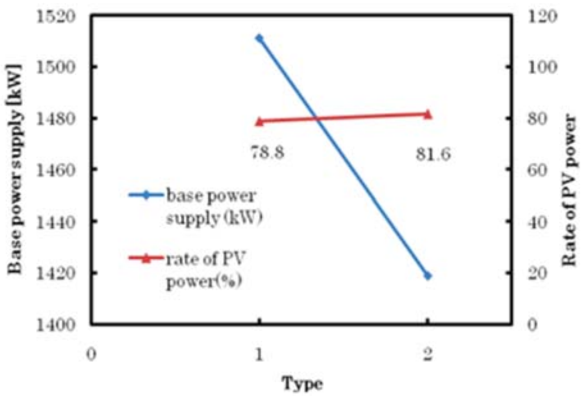

Fig.10: The base power supply.

Fig.10 shows the relationships among base power supply, Type 1 and Type 2 that discussed above: the base power supply of Type1 is 1,511 kW and Type 2 is 1,419 kW. The Type 1 can gain more base electric power whereas; more than 29 % of storage electric power loss can be reduced in the case of Type 2. The rate of PV power means the amount of electric power generated by PV system that is used as base power supply. The PV power rate of type1 is 78.8 % and Type 2 is 81.6 %. The base power supply of Type 2 is smaller than Type 1, conversely; the rate of PV power is larger than Type 1.

As shown in figures above, the base power supply has an output ability of 1,511 kW in Type1 or 1,419 kW in Type 2, which can be seen as 15.11 % or 14.19 % of the capacity of large-scale PV system (10 MW). It is generally recognized that PSS can be used as base electric power to supply to load, also to reduce or stop the output of nuclear or thermal power station.

5 Conclusion

In this paper, it is proposed a new method for PSS to store the electric power from PV system in the daytime and discharge in the nighttime as base power supply. The large-scale PV system with PSS is studied. The results indicate the base power supply has an output ability of 1,511 kW in Type1 or 1,419 kW in Type 2, which can be seen as 15.11 % or 14.19 % of the capacity of large-scale PV system (10MW). The point that requires clarification in detail is the installed position of PSS, the capacity of PSS, the capacity of transmission line, power generation cost, and base power supply. The results are follows:

(1) The capacity of PSS depends on installed position of PSS and it can be reduced if PSS is set up at middle side or load side. The capacity rate of PSS at middle side is 9.5 % lower and load side is 19% lower than that of PV side due to the power loss by distance of the transmission line.
(2) The capacity rate of transmission line at middle side and load side is approximately three times higher than that of PV side. The PSS should install at PV side so that the capacity of transmission line and cost can be reduced.
(3) The land and personnel cost in Tokyo (load side) is approximately 23.7 times and 1.7 times higher than Aomori (PV side) respectively, therefore: PSS should install in Aomori in order to reduce the land and personnel cost.
(4) PSS can be used as base power supply to satisfy demand and to reduce or stop the output of nuclear station or thermal power station. It is possible to use base power supply from PV power instead of electric power from nuclear station or thermal power station.
(5) It is believed that PSS will be used as energy storage system in large-scale PV system or renewable energy system in the future.

Acknowledgements:
This work was supported by H. Ito (East Japan Railway Co.). He simulated the large-scale PV System with pumped storage system by computer. We thank H. Ito for supporting deeply.

References:
[1] M. Şenol, S. Abbasoğlu, O. Kükrer and A. A. Babatunde, A guide in installing large-scale PV power plant for self consumption mechanism, *Solar Energy*, Vol.132, 2016, pp.518-537.
[2] Q. Meng, Y. Wang, L. Zhang, Irradiance characteristics and optimization design of a large-scale solar simulator, *Solar Energy*, Vol.85-9, 2011, pp.1758-1767.
[3] D. D. Milosavljević, T. M. Pavlović, D. LJ. Mirjanić and D. Divnić, Photovoltaic solar plants in the Republic of Srpska - current state and perspectives, *Renewable and Sustainable Energy Reviews*, Vol.62, 2016, pp.546–560.
[4] G. C. Bakos and D. A. Petroglou, Simulation study of a large scale line-focus trough collector solar power plant in Greece, *Renewable Energy*, Vol.71, 2014, pp.1-7.
[5] H. Ito and X. Che, Study on Electrical Storage Methods in Large-scale DC Photovoltaic Generation System, *Proc. of The Japan-Thailand Lao P.D.R Joint friendship International Conf. on Applied Electrical and Mechanical Eng.*, Thailand, 2011, pp.17-18.

[6] N. Sekiguchi and T. Tani, Fundamental Study on Photovoltaic / Fuel Cell Power Hybrid System, *T.IEE Japan,* Vol.117-B, No.3, 1997, pp.402-408 (in Japanese).

[7] H. Ito, X. Che, T. Yuji and T. Bouno, Study on large-scale PV system with power storage system, *Proc. of JSES/ JWEA Joint Conf.*, Japan, 2012, pp.167-170 (in Japanese).

[8] X. Che and Y. Kato, The Study on DC Community Grid-Connected PV System, *Chinese Solar Energy Society*, Vol.34-9, 2013, pp.1606-1611 (in Chinese).

[9] X. Che, T. Tani and F. Nakamura, “The construction Method of Photovoltaic Power System in the Community Area, *The Institute of Electrical Engineers of Japan*, Vol.120-2, 2000, pp.187-194 (in Japanese).

[10] X. Che, T. Fujisawa, T. Inaba and T. Tani, Introduction Effect of the New Grid-connected PV Systems in the Community Area, *Japan Solar Energy Society*, Vol.30-6, 2004, pp.41-46 (in Japanese).

[11] X. Che, “The cost analysis and design of new grid-connected PV system in the community area”, *Chinese solar energy society*, Vol.26-2, 2005, pp.207-214 (in Chinese).

[12] R. Aihara, A. Yokoyama, F. Nomiyama and N. Kosugi, Impact of Operational Scheduling of Pumped Storage Power Plant Considering Excess Power on Power Supply Reliability in a Power System with a Large Penetration of Photovoltaic Generations, *Journal of International Council on Electrical Eng.,* Vol.1-1, 2011, pp.85-90.

[13] R. Aihara, A. Yokoyama, F. Nomiyama and N. Kosugi, Optimal Operation Scheduling of Pumped Storage Hydro Power Plant in Power System with a Large Penetration of Photovoltaic Generations, *Journal of International Council on Electrical Eng.*, Vol.2-3, 2012, pp.283-289.

[14] T. Kuwabara, Design and dynamic response characteristic of 400MW adjustable speed pumped storage unit for Ohkawachi Power Station, *IEEE Trans. Energy Conversion,* Vol.11-2, 2002, pp.376-384.

[15] K. Sato and S. Wakao, Data Mining Method for Battery Operation Optimization in Photovoltaics, The Institute of Electrical Engineers of Japan, Vol. 130-3, 2010, pp.313-319.

[16] M. Shimizu and H. Sawai, Current Status and Future Development of PV Technology, SHARP TECHNICAL JOURANAL, Vol.93, 2005, pp.5-10 (in Japanese).

[17] NEDO Technical Information Data Base, ~~2008~~ 2008, Standard meteorology and solar radiation data (METPV-3), Retrieved from http://www.nedo.co.jp.

[18] M. Mae, A. Ito, T. Inoue, K. Muro, T. Tanaka, S. Hirayama and M. Sekizaki, Annial Sun and Monthly Fluctuation of Energy Consumption for Each Usage, J. Environ. Eng., AIJ, No.610, 2006, pp.91-98 (in Japanese).

Toshifumi Yuji was born in Miyazaki, Japan, on June 2, 1976. He received the M.E. degree from the University of Miyazaki, Miyazaki, Japan, in 2003 and the Ph.D. degree from the Tokyo Institute of Technology, Tokyo, Japan, in 2007. He became a Research Associate at Hiroshima National College of Maritime Technology in 2005 and Assistant Professor at Oita National College of Technology in 2006. He is currently a Lecturer in Faculty of Education and Culture, University of Miyazaki, Miyazaki, Japan.

Che Xiaoxuan was born in Hubei, China, in 1956. He received doctorate degree in Electrical Engineering from Tokyo University of Science in Japan in 2000. He is serving as a professor of Wuhan University, China, in 2008. He followed a professor of Tokyo Metropolitan University in 2010.

Toshio Bouno was born in Miyazaki, Japan, on October 30, 1955. He received the Ph.D. degree from the University of Miyazaki, Miyazaki, Japan in 2007. He became an associate professor at the Department of Electrical Engineering at the Salesian Polytechnic in 2012, and he became a Professor at the Department of Electrical and Electronic Engineering at National Institute of Technology, Sasebo College in 2017.

Noritsugu Kamata was born in Nagasaki, Japan, in 1979. He received the bachelor’s degree in electrical engineering from the University of Tokyo Denki, in 2002. He received the master degree in Electrical Engineering from King Mongkut’s University of Technology Thonburi, Thailand, in 2018.