20

Power Characteristics of Compound Microgrid Composed from PEFC and Wind Power Generation

Shin'ya Obara
Dep. of Electrical and Electric Eng., Power Eng. Lab., Kitami Institute of Technology
Japan

1. Introduction

It is predicted that a micro-grid technique is effective about a backup power supply in an emergency, a peak cut of power plants, and exhaust heat utilization. Furthermore, when renewable energy is connected to a micro-grid, there is potential to reduce the amount of greenhouse gas discharge (Abu-Sharkh *et al.*, 2006, Carlos & Hernandez, 2005, Robert, 2004). A micro-grid has an interconnection system with commercial power etc., and the independence supplying system of the power. The micro-grid with an interconnection system outputs and inputs the power between other grids. Therefore, the dynamic characteristic of the grid is influenced by the grid of a connection destination. When a micro-grid and a large-scale grid such as a commercial power system are interconnected, the dynamic characteristics of the power depend on the commercial power system. For this reason, in the micro-grid of the interconnection type, the option of the equipment to connect is wide. On the other hand, since micro-grid can reduce transportation loss of power and heat, this technique may become the major energy supply. The method of connecting two or more small-scale fuel cells and renewable energy equipment by a micro-grid, and supplying power to the demand side is effective in respect of environmental problems. So, this paper examines the independent micro-grid that connects fuel cells and wind power generation. In order to follow load fluctuation with an independent grid system, there are a method of installing a battery and a method of controlling the output of power generators. Since the battery is expensive, in this paper, it corresponds to load fluctuation by controlling the power output of the fuel cell. The output adjustment of the fuel cell has the method of controlling the production of electricity of each fuel cell, and the method of controlling the number of operations of the fuel cell. However, adjustment of the production of electricity of each fuel cell connected to the micro-grid may operate some fuel cell with a partial load with low efficiency. So, in this paper, the number of operations of fuel cells is controlled to follow fluctuations in the electricity demand.

In an independent micro-grid, a certain fuel cell connected to the micro-grid is chosen, and it is considered as a power basis. The power (voltage and frequency) of the other fuel cells is controlled to synchronize with this base power. Therefore, if the fuel cell that outputs base power is unstable, the power quality of the whole grid will deteriorate. Fuel cells other than base load operation are controlled to synchronize with the base power. The power quality

Source: Wind Power, Book edited by: S. M. Muyeen,
ISBN 978-953-7619-81-7, pp. 558, June 2010, INTECH, Croatia, downloaded from SCIYO.COM

(voltage and frequency) of the micro-grid depends on the difference in the demand-and-supply balance.
A 2.5 kW fuel cell is installed in one house of the micro-grid formed from ten houses. This fuel cell is operated corresponding to a base load. A 1 kW fuel cell is installed in seven houses, and a 1.5 kW wind power generator is connected to the micro-grid. According to the difference in electricity demand of the grid and power produced by the wind power generator, the number of operations of 1 kW fuel cells is controlled. A city gas reformer is installed in houses in which fuel cells are installed, and hydrogen is produced by city gas reforming. By adding random fluctuation to an average power load pattern, the power demand of a general residence is simulated and it uses for analysis. The dynamic characteristics of the micro-grid and the efficiency of the system that are assumed in this paper are investigated by numerical analysis.

2. Micro-grid model

2.1 System scheme

Figure 1 shows the fuel cell independent micro-grid model investigated in this paper. There is a network of the power and city gas in this micro-grid. Although a power network connects all houses, a city gas network connects houses in which a fuel cell is installed. The fuel cell installed in each house is a proton exchange membrane type (PEM-FC). The output of a 2.5kW fuel cell is decided to be a base power of the micro-grid. Moreover, PEM-FC of 1 kW power is installed in seven houses. However, the fundamental dynamic characteristics of all the fuel cells are the same, and a fuel cell and a city gas reformer are installed as a pair. One set of wind power generator is installed, and the power produced by wind force is supplied to a micro-grid through an inverter and an interconnection device. The power supply of the micro-grid assumes 50-Hz of the single-phase 200 V.

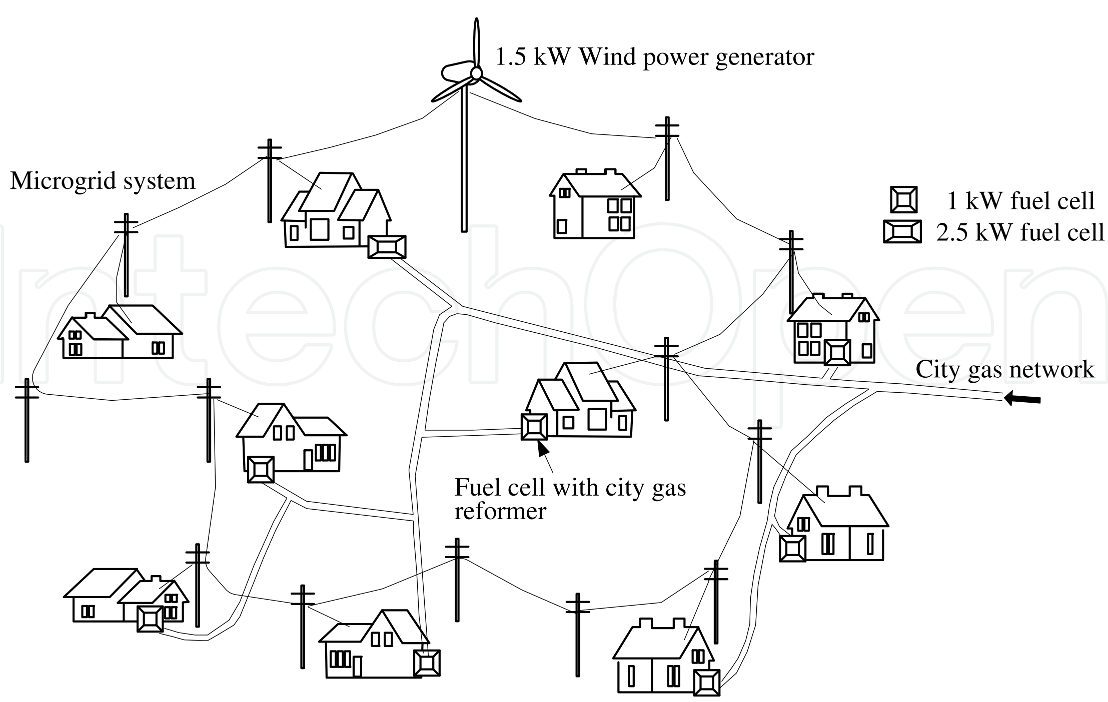


Fig. 1. Fuel cell micro-grid system with wind power generator

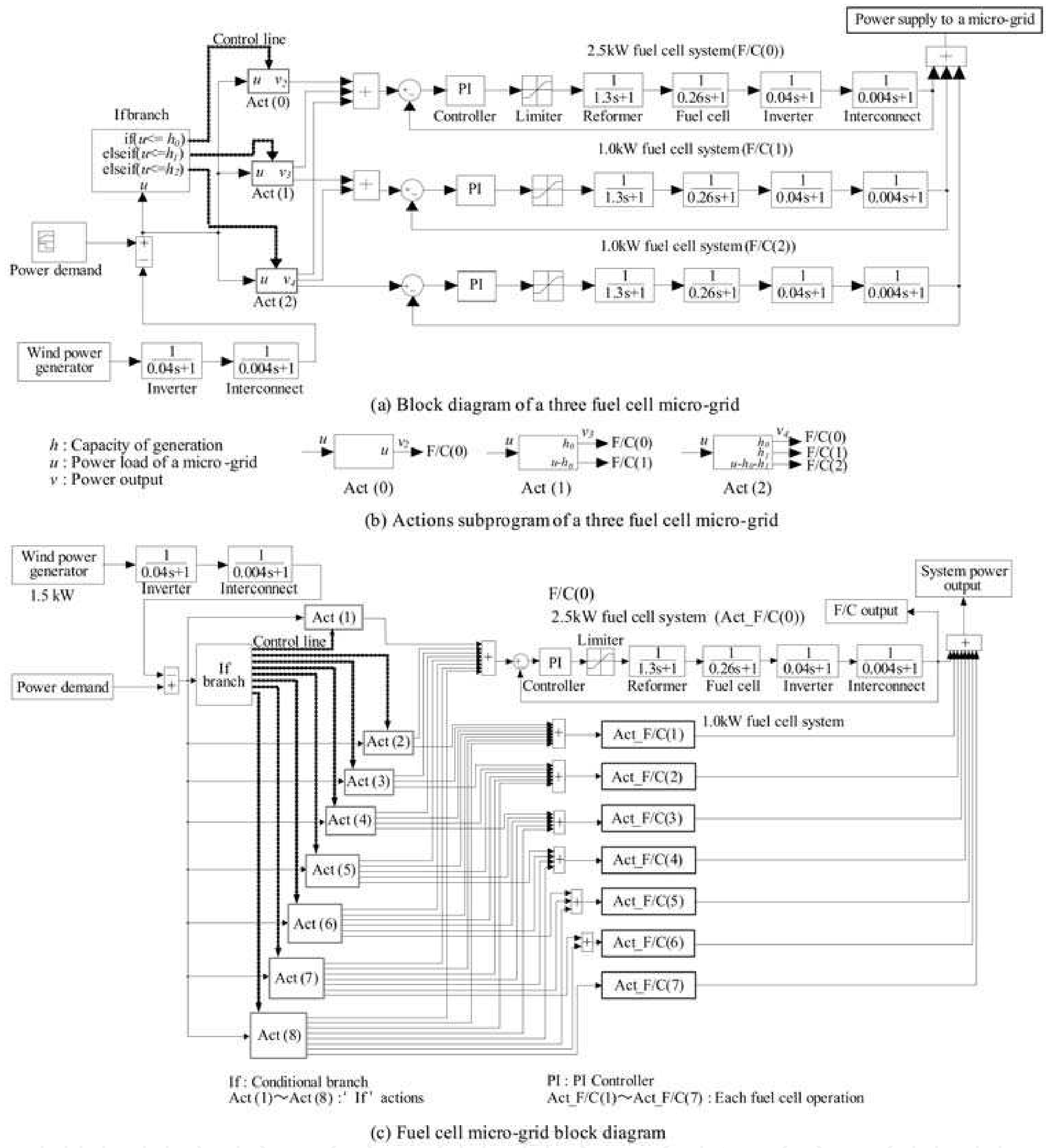


Fig. 2. System block diagram

2.2 System control

Figure 2 (a) is a block diagram of the micro-grid formed from three sets of fuel cell systems of F/C(0) to F/C(2) and one wind power generator. A fuel cell system consists of a controller, a power limitation device (Limiter), a reformer, a fuel cell, an inverter, and a system interconnection device. F/C(0) is a fuel cell corresponding to a base load, and operates F/C(1) and F/C(2) with the magnitude of load. The production of electricity required for F/C(2) from F/C(0) is taken as the value excluding the electric energy produced by wind power generation from the amount of electricity demand. The power of a

wind power generator is supplied to the grid through an inverter and a system interconnection device. Section 3.5 describes the dynamic characteristics of an inverter and a system interconnection device. The power generated by each fuel cell is decided by "If branch" and Act(0) to Act(2) in Fig. 2(a). Figure 2(b) shows the input and output of each block of Act(0) to Act(2). u expresses the power load and v_2 to v_4 expresses the output power in the block (from Act(0) to Act(2)) that branches in the magnitude of u. Moreover, h_0 and h_1 express the power generation capacity of the fuel cell of F/C(0) and F/C(1), respectively. In this system, when the value of u exceeds capacity h_0 of F/C(0), F/C(1) is operated first. F/C (2) is operated when the production of electricity is still less than the value of u. Thus, the number of operations of a fuel cell is controlled by the magnitude of the load added to the grid. The value except the power produced by wind power generation from electricity demand is the production of electricity required of fuel cell systems. Act(0) to Act(2) is chosen from magnitude (u) of the load, and the capacities of the fuel cells under IF conditions. In Act (0) to Act (2), as Fig. 2 (b) shows, the production of electricity of each fuel cell is calculated and outputted. Controlling each fuel cell by PI controller, a limiter limits the production of electricity of a fuel cell. The next section describes each dynamic characteristic of a reformer, a fuel cell, an inverter, and a system interconnection device.
Figure 2 (c) is a block diagram of the system installed in the micro-grid shown in Fig. 1. This system extends the system shown in Fig. 2 (a). F/C (0) is a 2.5-kW fuel cell corresponding to a base load, and F/C (1) to F/C (7) is a 1-kW fuel cell. Moreover, a wind power generator of 1.5-kW is connected to the grid. The dynamic characteristics of a fuel cell system are decided using the dynamic characteristics of a reformer, a fuel cell, and an inverter, and the control variables of a controller and a limiter. This paper shows the dynamic characteristics of each device with the transfer function of a primary delay system, described in the following section. Each parameter of PI control (proportional control (P) and integral control (I)) is given to the controller of a fuel cell system beforehand, and each fuel cell system is controlled.

3. Response characteristic of system configuration equipment

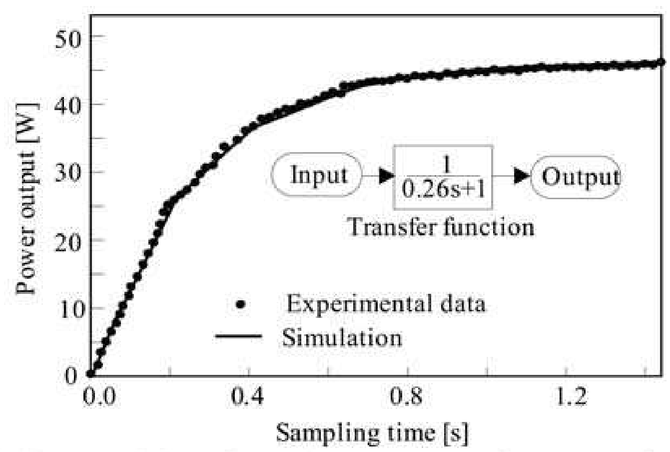
3.1 Power generation characteristic of fuel cell

Figure 3 (a) shows the result of measurement when inputting a load of 45 W into the testing equipment of PEM-FC (maximum output 100 W) stepwise. In the test, the ambient temperature was set to 293 K, and reformed gas and air were supplied to an anode and a cathode, respectively. An approximated curve is prepared from the result of the measurement in Figure 3 (a), and the transfer function of a primary delay is obtained. Strictly, although a transfer function is considered depending on the load factor, it is not taken into consideration because this difference is small by test results.

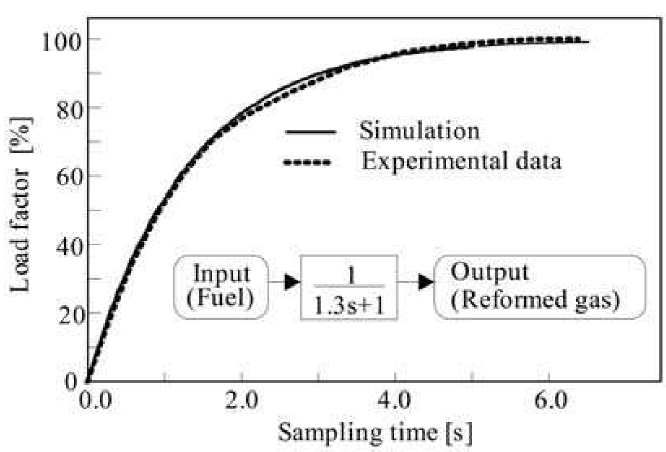
3.2 Output characteristics of city gas reformer

Figure 3 (b) shows the output model that inputted a load of 100% load factor into the city gas reformer stepwise (Nagano, 2002, Obara & Kudo, 2005, Lindstrom & Petterson, 2003, Oda. 1999, Takeda. 2004, Ibe. 2002). An approximated curve is prepared from the result of the measurement, and the transfer function of the primary delay of the city gas reformer is obtained. As a fuel cell, although the transfer function of a city gas reformer influences the magnitude of the load significantly, since there is no large difference, the result of Figure 3

(b) is used. Compared with the condition of the steady operation of the reformer, the characteristics of a startup and a shutdown differ greatly. Cold start operation and shutdown operation require about 20 minutes, respectively. In the analysis of this paper, it is assumed that the startup of the methanol reformer is always a hot start.



(a) Characteristics of transient response for a PEM fuel cell



(b) Characteristics of transient response of a reformer

Fig. 3. Response characteristics of system configuration equipment (Oda. 1999, Takeda. 2004, Ibe. 2002)

3.3 Power generation characteristics of wind power generation

The model of power obtained by wind power generation is decided at random between 0 to 1.5 kW for every sampling time, as shown in Figure 4 (a). The power of wind power generator is supplied to a micro-grid through an inverter and a system interconnection device. Figure 4 (b) shows the output model of the wind power generator through an inverter and a system-interconnection device. Because influence is taken in the dynamic characteristic of an inverter and a system-interconnection device, the output of wind power generation is settled on a width of 0.75 kW ±0.25 kW range, as shown in Figure 4 (b). The details of the transfer function of an inverter and a system interconnection device are given with Section 3.5. The dynamic characteristics of the inverter and system interconnection device significantly influence the power output characteristics of wind power generation.

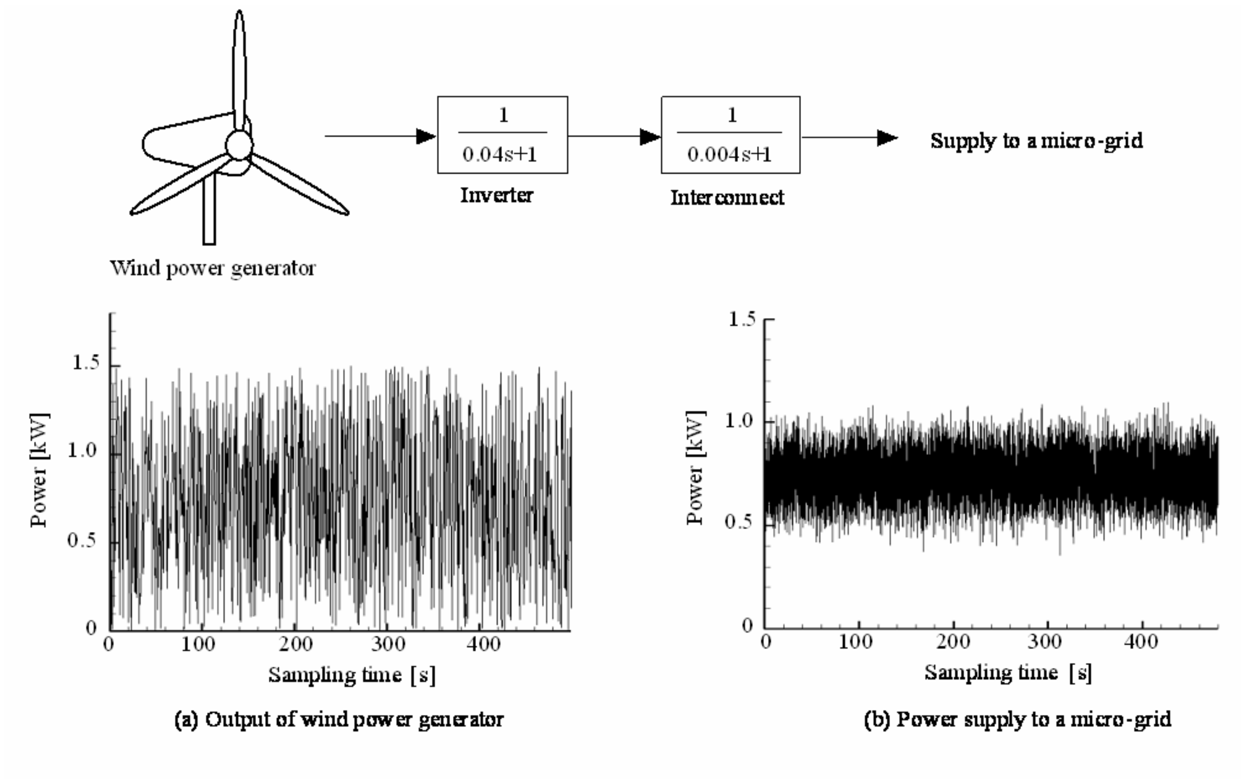


Fig. 4. Output model of wind power generator

3.4 Generation efficiency of the fuel cell system

Figure 5 shows a model of the relation between the load factor of a fuel cell, and generation efficiency (Obara & Kudo, 2005, 2005). Power-generation efficiency is obtained by dividing "the power output of the fuel cell system" by "the city gas calorific power supplied to the system." This model was prepared from the results of the power output when attaching the fuel cell show in Figure 3 (a) to the city gas reformer show in Figure 3 (b). If the load of a fuel cell is given to Figure 5, power generation efficiency is calculable. The maximum efficiency of one set of a fuel cell system is 32%.

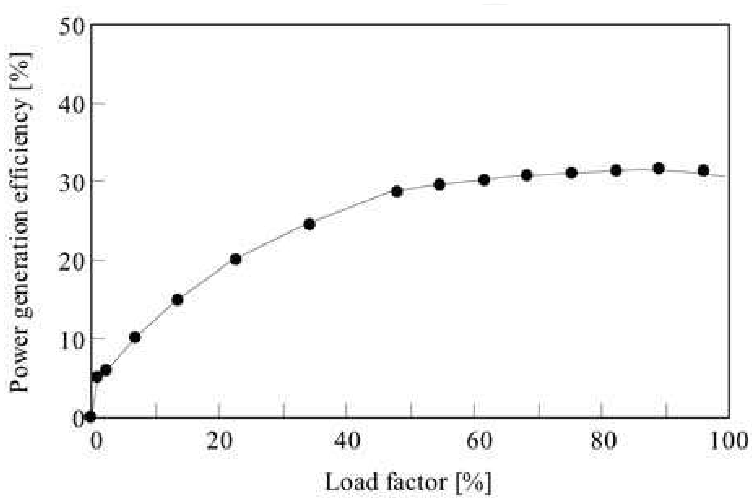


Fig. 5. Output characteristics of a PEM-FC with city-gas reformer

3.5 Inverter and system interconnection device

It is assumed that an inverter of a voltage control type is used, and 120 ms is required to output power on regular voltage and frequency (in this paper, it is less than 95%) (Kyoto Denkiki Co., Ltd. 2001). Figure 6 (a) expresses the transfer function of such an inverter with primary delay.

When changing power with a system interconnection device, the change takes about 10μs (Kyoto Denkiki Co., Ltd. 2001). However, there is the operation of taking the synchronism of the frequency between systems, and the model of the system interconnection device sets the change time to 12 ms. As a result, the transfer function of the system interconnection device by primary delay is shown Figure 6 (b).

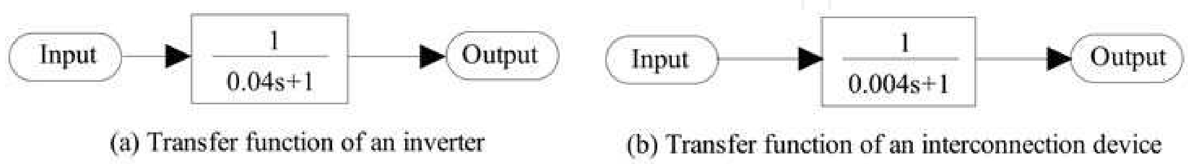


Fig. 6. Transfer function of an inverter and interconnection device

4. Control parameters and analysis method

The response characteristics of the 1 kW fuel cell system when inputting 0.2, 0.6, and a 1.0 kW load stepwise is shown in Figure 7. The response characteristics of a fuel cell system changes by the control parameters set up with the controller. As shown in Figure 7 (c), in 1 kW step input, the rising time and settling time (time to converge on ±5% of the target output) are not based on control parameters. In 0.2 kW step input, the rise time of "P = 12.0,

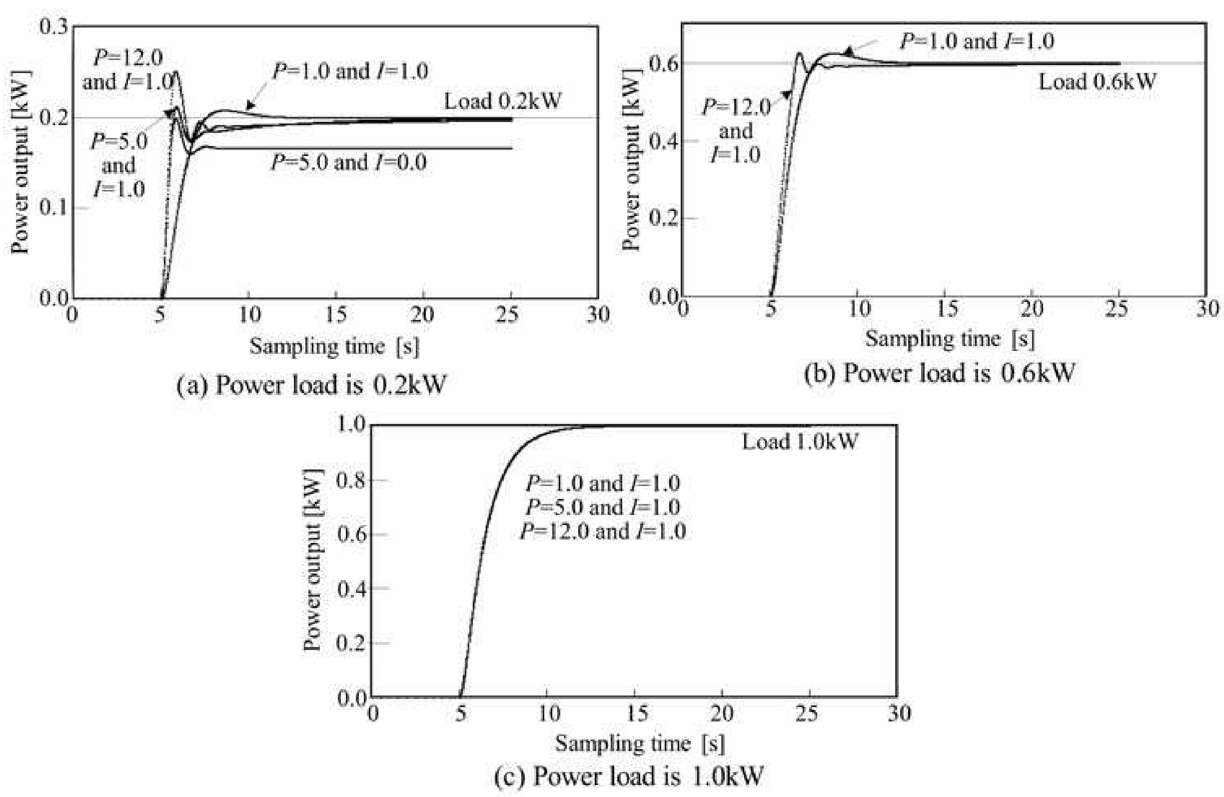


Fig. 7. Characteristics of electric power output of the system (Obara. 2005)

I = 1.0" is short, and the settling time of "P = 1.0, I = 1.0" is short. In 0.6 kW step input, "P = 12.0, I = 1.0", and "P = 1.0, I = 1.0" have almost the same settling time. Moreover, overshooting is large although the rise time of "P = 12.0, I = 1.0" is short. Considering the following load fluctuations, the control parameters of the fuel cell are analyzed by "P = 12.0, I = 1.0." The dynamic characteristics of a micro-grid are analyzed using MATLAB (Ver.7.0) and Simulink (Ver.6.0) of Math Work Corporation. However, in analysis, the solver to be used is the positive Runge-Kutta system, and this determines the sampling time from calculation converged to less than 0.01% by error.

5. Control parameters and analysis method

5.1 Step response

The response results when applying the stepwise input of 2, 4, 6 or 8 kW to the micro-grid at intervals of 30 seconds are shown in Figure 8 (a). The left-hand side in Figure 8 (a) shows the result of not installing a wind power generator. The right-hand side of the figure shows the result of a installing wind power generator. The maximum power by a overshooting and settling time (time to converge on ±5% of the target output) are described on the left-hand of Figure 8 (a). Moreover, the maximum power due to over shoot is described in the right-hand side figure. The settling time when not installing a wind power generator has the longest

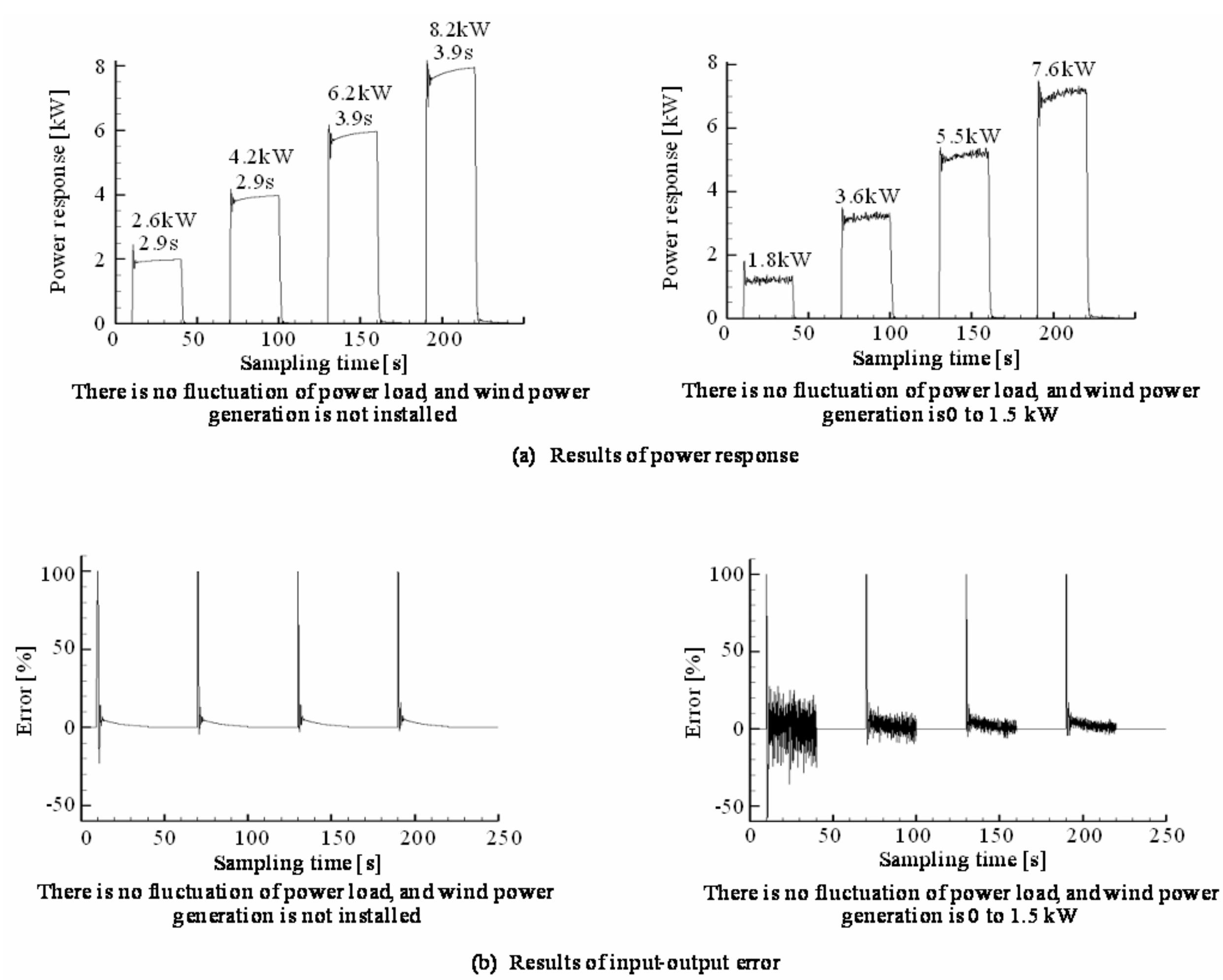


Fig. 8. Results of step response

period of step input of 6 kW and 8 kW for 3.9 seconds. If a wind power generator is connected to the micro-grid, many fluctuations in the system response characteristics will occur in a short period. If the power produced by wind power generation is supplied to the micro-grid, the dynamic characteristics of power of the micro-grid will be influenced. Figure 8 (b) shows the analysis result of the response error corresponding to Figure 8 (a). If wind power generator is connected to the grid, the response error will become large as the load of the grid becomes small. It is expected that the power range of the fluctuation of the micro-grid will increase as the output of the wind power generation grows. Therefore, when the load of a micro-grid is small compared with the output of wind power generator, the power supply of the independent micro-grid becomes unstable.

5.2 Load response characteristics of cold region houses

Figure 9 (a) shows the power demand pattern of a micro-grid formed from ten individual houses in Sapporo in Japan, and assumes a representative day in February (Narita, 1996). This power demand pattern is the average value of each hour, and the sampling time of analyses and the assumption time are written together on the horizontal axis. As a base load of the power demand pattern shown in Fig. 9 (a), F/C (0) is considered as operation of 2.5 kW constant load. Figure 9 (b) and (c) are the power demand patterns when adding load fluctuations (±1 kW and ±3 kW) to Fig. 9 (a) at random. The variation of the load was decided at random within the limits of the range of fluctuation for every sampling time.

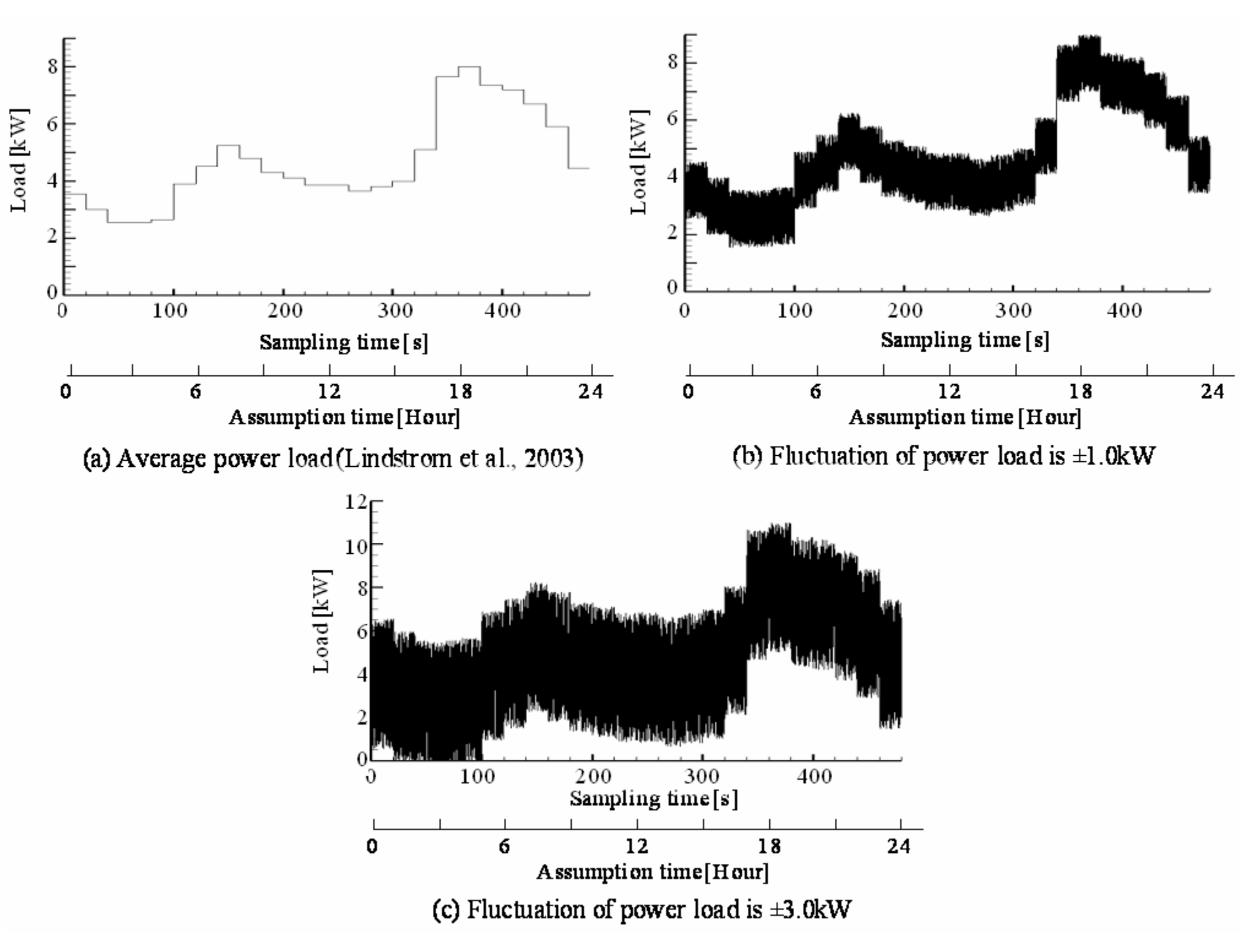


Fig. 9. 480s demand model for 10 houses in February in Sapporo

Figure 10 shows the response results of F/C (0) to F/C (6) when wind power generation is connected to the micro-grid and the power load has ±1 kW fluctuations. F/C (0) assumed operation with 2.5 kW constant output, with the result that the response of F/C (0) is much less than 2.5 kW in less than the sampling time of 100 s as shown in Figure 10 (a). This reason is because F/C (0) was less than 2.5 kW with the power of wind power generation. Although the micro-grid assumed in this paper controlled the number of operations of F/C (1) to F/C (7) depending on the magnitude of the load, since the power supply of wind power generation existed, there was no operating time of F/C (7).

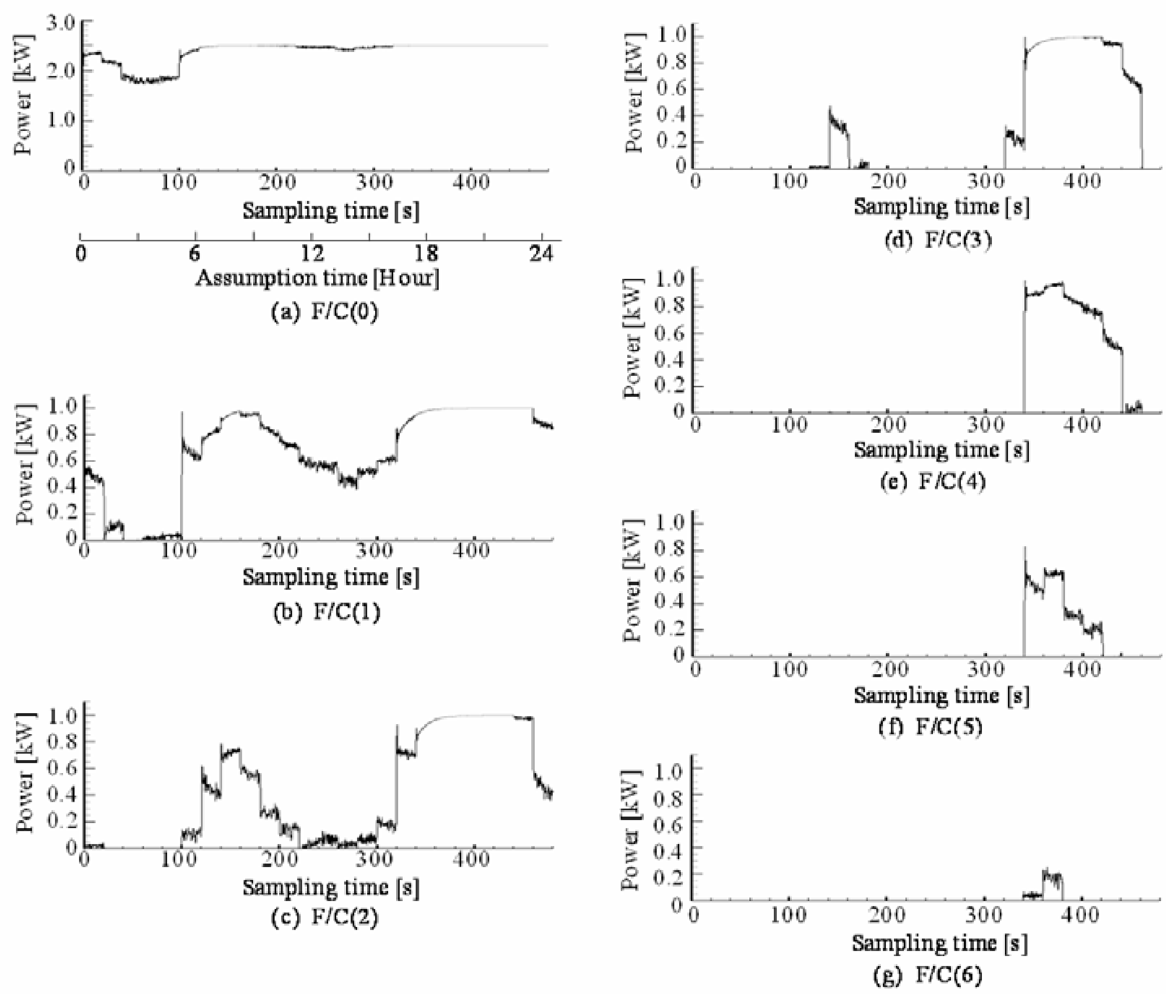


Fig. 10. Response results of each fuel cell

5.3 Power generation efficiency

Figure 11 shows the analysis results of the average power generation efficiency of fuel cell systems for every sampling time. The average efficiency of a fuel cell system is the value averaging the efficiency of F/C (0) to F/C (7) operated at each sampling time. However, the fuel cell system to stop is not included in average power generation efficiency. The average power generation efficiency of Figure 11 (a) is 13.4%, and Figure 10 (b) shows 14.3%. The difference in average efficiency occurs in the operating point of a fuel cell system shifting to the efficient side, when load fluctuations are added to the micro-grid. Thus, if load fluctuations are added to the micro-grid, compared with no load fluctuations, the load factor of the fuel cell system shown in Figure 4 will increase.

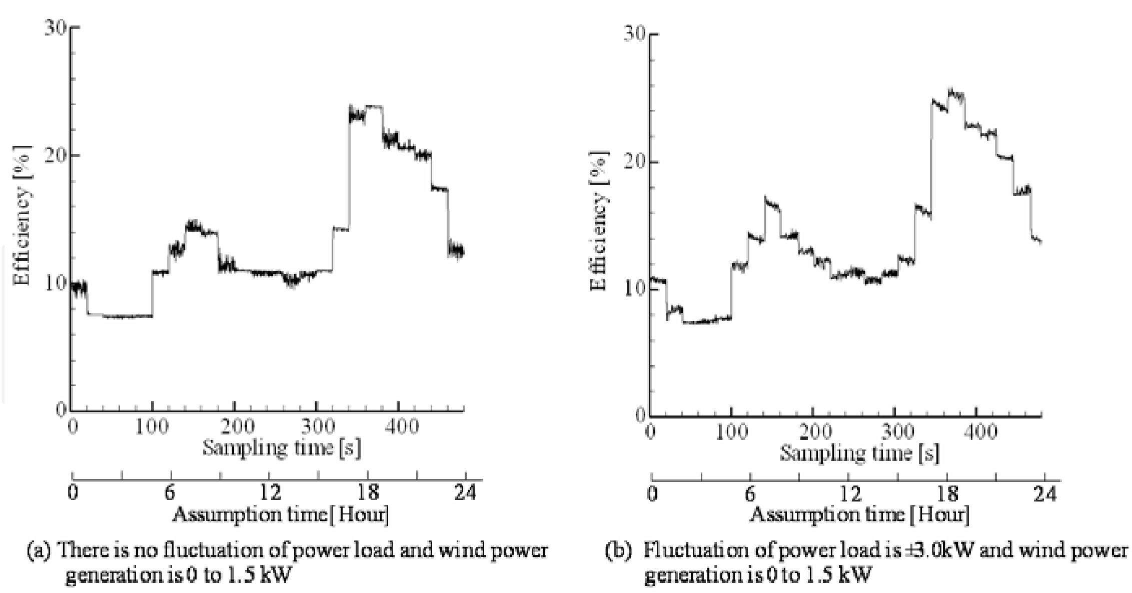


Fig. 11. Results of micro-grid average efficiency

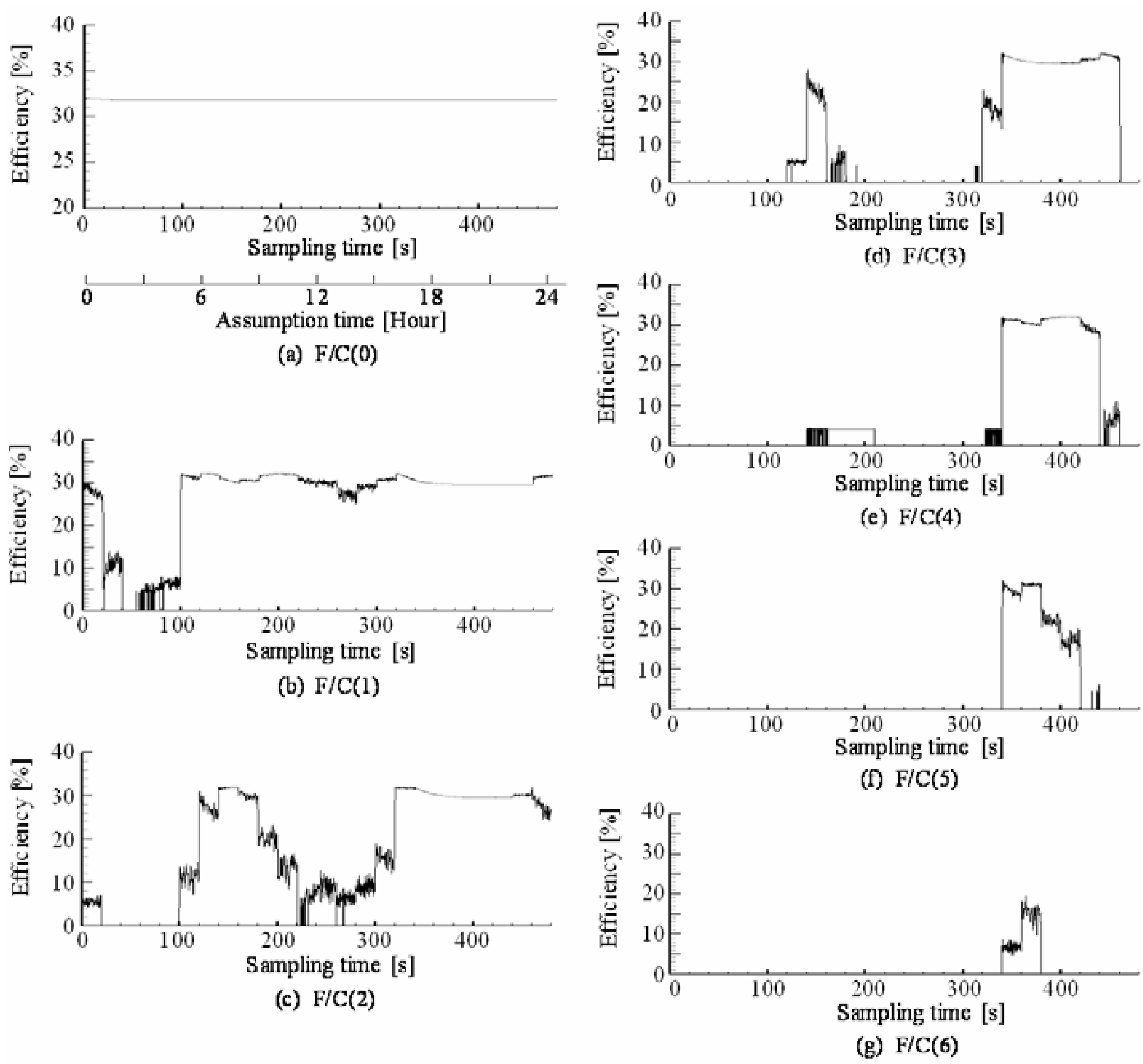


Fig. 12. Results of efficiency for each fuel cell

Figure 12 shows the power generation efficiency of each fuel cell in the case of connecting wind power generation to the micro-grid of ±1.0kW of load fluctuation. F/C (0) operated corresponding to a base load has maximum power generation efficiency at all sampling times. Since the number of operations of a fuel cell is controlled by the magnitude of the load added to the micro-grid, the operating time falls in the order of F/C (1) to F/C (6). Moreover, there is no time to operate F/C (7) in this operating condition.
The relation between the range of fluctuation of the power load and the existence of wind power generation, and the amount of electricity demand of a representative day is shown Fig. 13. When the load fluctuation of the power is large, although the power demand amount of the micro-grid on a representative day increases slightly, it is less than 2%. Moreover, when installing wind power generation, the power demand amount of the micro-grid of a representative day decreases compared with the case of not installing. This decrement is almost equal to the value that integrated the power (average of 0.75 kW) supplied to a grid by the wind power generation of Fig. 4 (b).

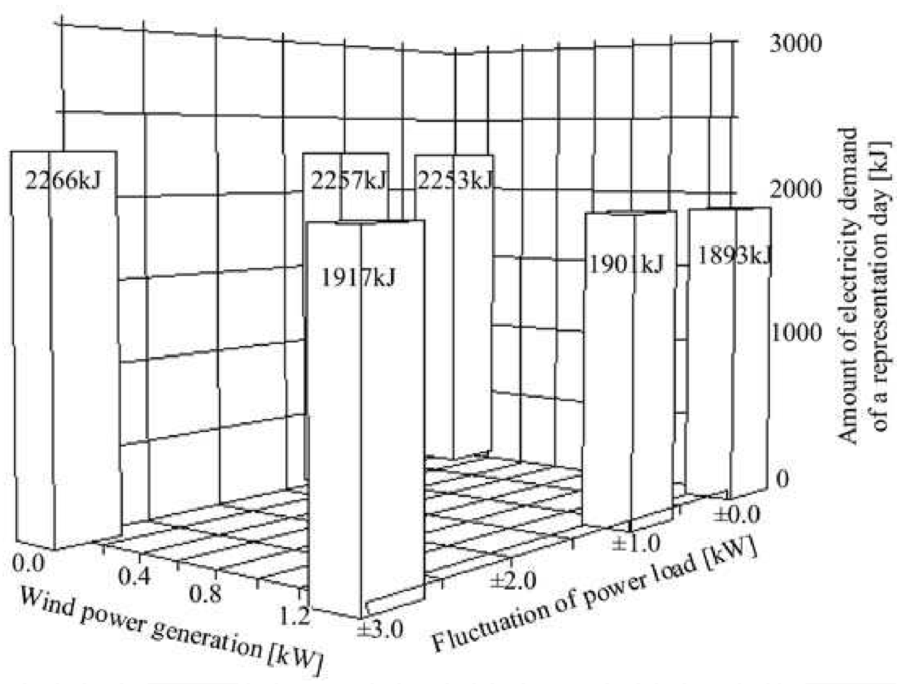


Fig. 13. Amount of 480s demand model with power fluctuation and wind power generation

Figure 14 shows the range of fluctuation of power load and the existence of wind power generation, and the relation to city gas consumption on a representative day of the micro-grid. If the range of fluctuation of the power load becomes large, city gas consumption will decrease. This is because electric power supply cannot follow the load fluctuations of the micro-grid if the range of fluctuation of the power load is large. Moreover, in ±3 kW of load fluctuation, some loads become zero (it sees from 20s to 100s of sampling times) and city gas consumption lowers. In ±3 kW of load fluctuation of the power, it is expected that the power of a micro-grid is unstable and introduction to a real system is not suitable.

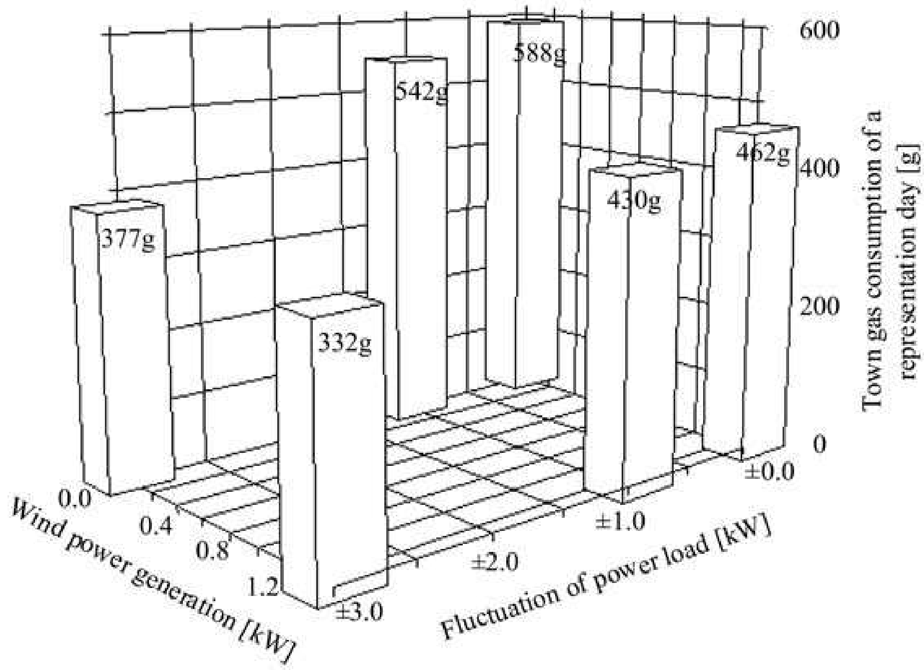


Fig. 14. Analysis result of town gas consumption for 480s demand model with power fluctuation and wind power generation

6. Conclusions

A 2.5 kW fuel cell was installed in a house linked to a micro-grid, operation corresponding to a base load was conducted, and the dynamic characteristics of the grid when installing a 1 kW fuel cell system in seven houses were investigated by numerical analysis. A wind power generator outputted to a micro-grid at random within 1.5 kW was installed, and the following conclusions were obtained.

1. Although the settling time (time to converge on ±5% of the target output) of the micro-grid differs with the magnitude of the load, and the parameters of the controller, it is about 4 seconds.
2. When connecting a wind power generator to the micro-grid, the instability of the power of the grid due to supply-and-demand difference is an issue. This issue is remarkable when the load of an independent micro-grid is small compared to the production of electricity of unstable wind power generation.
3. When wind power equipment is connected to the micro-grid with load fluctuation, the operating point of the fuel cell system may shift and power generation efficiency may improve.

7. Acknowledgements

This work was partially supported by a Grant-in-Aid for Scientific Research(C) from the JSPS.KAKENHI (17510078).

8. Nomenclature

Act : ’’ If “ action

Act_FC	:	Each fuel cell operation
F/C	:	Fuel cell
h	:	Capacity of generation W
I	:	Integral parameter
P	:	Proportionality parameter
PI	:	Proportion integration control
u	:	Power load of a micro-grid W
ν	:	Power output W

9. References

Abu-Sharkh, S.; Arnold, R. J.; Kohler, J.; Li, R.; Markvart, T.; Ross, J. N.; Steemers, K.; Wilson, P. & Yao, R. (2006). Can microgrids make a major contribution to UK energy supply?. *Renewable and Sustainable Energy Reviews*, Vol. 10, No. 2, pp. 78-127.

Carlos, A. & Hernandez, A. (2005). Fuel consumption minimization of a microgrid. *IEEE Transactions on Industry Applications*, Vol. 41, No. 3, pp. 673- 681.

Ibe, S.; Shinke, N.; Takami, S.; Yasuda, Y.; Asatsu, H. & Echigo, M. (2002). Development of Fuel Processor for Residential Fuel Cell Cogeneration System, *Proc. 21th Annual Meeting of Japan Society of Energy and Resources*, pp. 493-496, Osaka, June 12-13, ed., Abe, K. (in Japanese)

Kyoto Denkiki Co., Ltd. *A system connection inverter catalog and an examination data sheet*, 2001.

Lindstrom, B. & Petterson, L. (2003). Development of a methanol fuelled reformer for fuel cell applications, *J. Power Source*, Vol. 118, pp. 71-78.

Nagano, S. (2002). Plate-Type Methanol Steam Reformer Using New Catalytic Combustion for a Fuel Cell. *Proceedings of SAE Technical Paper Series*, *Automotive Eng*. pp. 10.

Narita, K. (1996). The Research on Unused Energy of the Cold Region City and Utilization for the District Heat and Cooling. *Ph.D. thesis*, Hokkaido University, Sapporo. (in Japanese)

Obara, S. & Kudo, K. (2005). Installation Planning of Small-Scale Fuel Cell Cogeneration in Consideration of Load Response Characteristics (Load Response Characteristics of Electric Power Output). *Transactions of the Japan Society of Mechanical Engineers*, Series B; Vol. 71, No.706, pp. 1678-1685. (in Japanese)

Obara, S. & Kudo, K. (2005). Study on Small-Scale Fuel Cell Cogeneration System with Methanol Steam Reforming Considering Partial Load and Load Fluctuation. *Transactions of the ASME*, *Journal of Energy Resources Technology*, Vol. 127, pp. 265-271.

Oda, K.; Sakamoto, S.; Ueda, M.; Fuji, A. & Ouki, T. (1999). A Small-Scale Reformer for Fuel Cell Application. *Sanyo Technical Review*, Vol. 31, No. 2, pp. 99-106, Sanyo Electric Co., Ltd., Tokyo, Japan. (in Japanese)

Robert, H. (2004). Microgrid: A conceptual solution. *Proceedings of the 35th Annual IEEE Power Electronics Specialists Conference*, Vol. 6, pp. 4285-4290.

Takeda, Y.; Iwasaki, Y.; Imada, N. & Miyata, T. (2004). Development of Fuel Processor for Rapid Start-up, *Proc. 20th Energy System Economic and Environment Conference*, Tokyo, January 29-30, ed., K. Kimura, pp. 343-344. (in Japanese)

Wind Power

Edited by S M Muyeen

ISBN 978-953-7619-81-7
Hard cover, 558 pages
Publisher InTech
Published online 01, June, 2010
Published in print edition June, 2010

This book is the result of inspirations and contributions from many researchers of different fields. A wide verity of research results are merged together to make this book useful for students and researchers who will take contribution for further development of the existing technology. I hope you will enjoy the book, so that my effort to bringing it together for you will be successful. In my capacity, as the Editor of this book, I would like to thanks and appreciate the chapter authors, who ensured the quality of the material as well as submitting their best works. Most of the results presented in to the book have already been published on international journals and appreciated in many international conferences.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Shin'ya Obara (2010). Power Characteristics of Compound Microgrid Composed from PEFC and Wind Power Generation, Wind Power, S M Muyeen (Ed.), ISBN: 978-953-7619-81-7, InTech, Available from: http://www.intechopen.com/books/wind-power/power-characteristics-of-compound-microgrid-composed-from-pefc-and-wind-power-generation

INTECH
open science | open minds

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821