A NEW COORDINATED CONTROL SCHEME OF SEAWATER DESALINATION PLANT AND DIESEL ENGINE GENERATORS FOR SECURING REGULATING CAPACITY IN ISLAND POWER SYSTEM WITH RENEWABLE ENERGY GENERATION

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Abstract – This paper presents a new coordinated control scheme of a seawater desalination plant as a controllable load and diesel engine generators for operation of a small island power system. Recently, more renewable energy based generations have been installed into small islands. However, their intermittent outputs may cause large system frequency fluctuation because of the shortage of regulating capacity. In this paper, the power consumption of the seawater desalination plant is controlled for improving the economy of the power system operation and securing more regulating capacity.

Keywords: Island Power System, Load Frequency Control, Regulating Capacity, Renewable Energy, Seawater Desalination Plant.

1 INTRODUCTION

There are many islands in Japan and some of them cannot have the interconnection line with other power grids because they are too far from one another. Oil-fired generators in small islands such as diesel engine generators are usually used to achieve the balance in power supply and demand. However, their generation cost is very high and their emissions are not environmentally friendly. In order to solve these problems, renewable energy based generations such as photovoltaic generation or wind power generation have been installed into isolated islands in recent years. However, they cannot supply power with smooth changes and there is a concern that the installation of them may bring about large fluctuation of system frequency due to the shortage of regulating capacity in an island.

Nowadays, many researches on contribution of controllable loads e.g. heat pump water heaters and electric vehicles to load frequency control are studied for the reduction of energy storage system installation[1][2]. In this research, a seawater desalination plant is focused as a controllable load in a small island and the power control scheme of a seawater desalination plant for securing regulating capacity is proposed [3] [4].

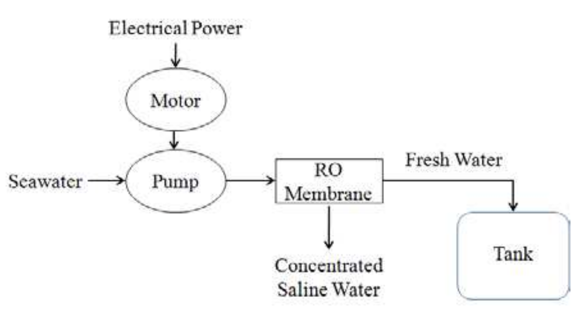


Figure 1: Components of seawater desalination plant.

2 SEAWATER DESALINATION PLANT

In some small islands, it is very difficult to secure fresh water because they neither have rivers nor ponds suited for fresh water. In this case, the fresh water is supplied to the residents by the use of a seawater desalination plant, which converts seawater into fresh water by removal of salts. It consists of a high pressure pump, an RO (Reverse Osmosis) membrane, and a storage tank of fresh water, as shown in Fig. 1. The operator controls the amount of fresh water to be produced based on the storage in the tank. In other words, the input power of the seawater desalination plant can be changed as long as the daily operation is not disturbed. In this paper, a method to control the amount of fresh water production, which is related to the power consumption of the high pressure pump, is proposed for the power system operation. It is assumed that the power consumption of the high pressure pump can be changed continuously and rapidly by the control of the inverter.

3 SIMULATION MODELS

3.1 Power System Model

The power system model consists of 3 diesel engine generators (DEGs), 8 small flywheel energy storage systems (FESS), a wind turbine generator (WTG), a seawater desalination plant and other local loads. This model is based on a real island power system, Hateruma-jima, Okinawa prefecture, Japan. The maximum and the minimum output or input powers of each machine are shown in Table 1. The inverter control system has not been applied into the desalination plant in Hateruma-jima yet. However, many motor drive controls with inverter have so far been installed in various kinds of motor system applications and the inverter control system can be expected to be applied into the seawater desalination plant in the future. Therefore, it is assumed in this paper that the high pressure pump of the seawater desalination plant has the motor drive control with the inverter as mentioned above.

In this power system, the large WTG is installed and only diesel engine generators may not compensate the whole power fluctuation. Therefore, FESSs are installed to suppress the short-term power fluctuation. The amount of the energy storage of the FESS (8 Total) is ±190kW × 19sec when the state of charge (SOC) is 50%. Their response characteristic is represented as the 0.1second first-order time lag model.

In this power system model, 3 diesel engine generators have different speed governor systems because of the governor system installed in each generator. Generator 3 has quicker response than other two generators.

3.2 Generation Planning of Isolated Power System

In many of isolated island systems, generation planning is based on the knowledge of on-site operators, and there are no clear standards for it. In this paper, the generation schedule is planned by the processes shown in Fig. 2. It is updated every 1 minute.

At first, a forecasted output of the wind turbine generator is calculated based on the average wind velocity over previous 5 minutes. Next, the reference output of diesel engine generators for the next minute is calculated based on the forecasted output of the wind turbine generator and the forecasted load. Finally, the On-Off state of the wind turbine generator and reference outputs of each diesel engine generator are determined. At the same time, On-Off of diesel generators 3 minutes ahead is also determined, for the consideration of the preparation time of starting up.

The following four constraints are considered here.

(I) On-Off condition of diesel engine generators

When the reference outputs of diesel engine generators come below 60% of the rated capacity, a generator is shut down. When the reference output goes over 90%, a new generator starts.

(II) The number of operating diesel engine generators

The minimum number of operating diesel engine generators is 2. In case that the number of operating diesel engine generators should be adjusted to only 1, the wind turbine generator is forced to stop its operation.

(III) Restart of a wind turbine generator

The wind turbine generator can restart when its restart does not change the number of the operating diesel engine generators.

(IV) The minimum preparation time of starting up

It is assumed that the minimum preparation time of the diesel engine generators is 30 minutes. For example, when a diesel engine generator is shut down, it cannot be driven again for at least next 30 minutes. On the other hand, the preparation time of starting up of wind generation is not considered.

3.3 Compatibility of Economy of Power System Operation and Regulating Capacity

As for the reference outputs of each diesel engine generator, the regulating capacity is also important. In terms of the load frequency control, it is more effective for generators with quicker response to secure as much controllable margin as possible than for all generators to secure it respectively. Moreover, required regulating capacity for the compensation of short-term power fluctuation strongly depends on the wind velocity fluctuation. In order to cope with both the fuel costs minimization and securing regulating capacity, the following methods are used for the calculation of each reference output of DEGs.

At first, required regulating capacity is calculated based on the WTG output fluctuation forecast and load fluctuation forecast. The WTG output fluctuation forecast is determined based on the average wind velocity

Table 1: Output power limits of system components.

	Minimum Power[kW]	Maximum Power[kW]
Generator 1	75	150
Generator 2	75	150
Generator 3	150	300
WTG	0	275
FESS(8 Total)	-190	190
Seawater Desalination Plant	-80	-20

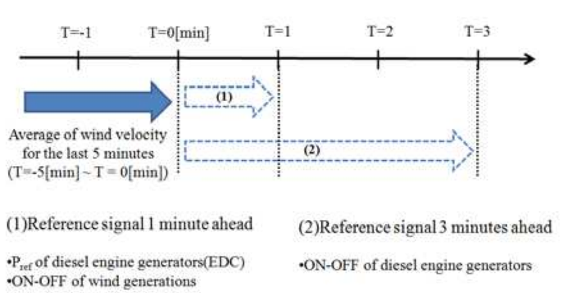


Figure 2: Generation planning model in isolated power system.

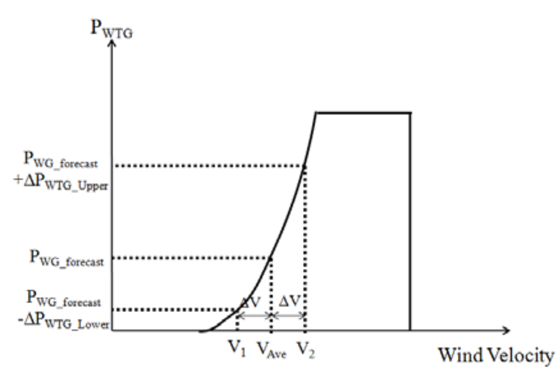


Figure 3: WTG fluctuation forecast.

over previous 5 minutes and WTG power curve shown in Fig. 3. ΔV is the short-term fluctuation forecast of wind velocity and it is always 2 m/s in this paper. Consequently, ΔP_{WTG_Lower} is set for lower regulating capacity and ΔP_{WTG_Upper} is set for upper regulating capacity as shown in Fig. 3. Next, the load fluctuation forecast ΔP_{Load} is calculated. In this paper, ΔP_{Load} is assumed to be always 10[kW] for the simplicity of simulations. Finally, required regulating capacity P_{Lower_cap} and P_{Upper_cap} can be calculated with equations (1) and (2).

$$P_{Lower\_cap} = \sqrt{\Delta P_{WTG\_Lower}^{\ 2} + \Delta P_{Load}^{\ 2}} \tag{1}$$

$$P_{Upper\_cap} = \sqrt{\Delta P_{WTG\_Upper}^{\ 2} + \Delta P_{Load}^{\ 2}} \tag{2}$$

Next, the reference outputs of each diesel engine generator are calculated based on the following condition. In this paper, DEGs are divided into two groups based on the response speed quicker-response generators and slower-response generators, i.e., governor speed regulation of quicker-response generators have larger than that of slower-response generators. Generator 3 is classified into quicker-response generators and Generator 1 and Generator 2 are classified into slower-response generators. Required regulating capacity should be secured by the quicker-response generators as much as possible for the effective load frequency control. In this paper, generation planning problem is solved with the consideration of the constraints on required regulating capacity of quicker-response generators.

Objective function
- Fuel cost minimization

Constraints
- Supply and demand power balance
- Controllable margin of DEGs
- On-Off of DEGs
- Required regulating capacity of quicker-response generators

However, it is possible that supply and demand power balance constraint cannot be satisfied because of the shortage of required regulating capacity. To avoid this case, the required regulating capacity is decreased step by step in this case as shown in Fig. 4.

3.4 Frequency Analysis Model

In order to calculate the system frequency, a frequency analysis model shown in Fig. 5 is used [5]. This model is the transfer function model based on the deviation from a given operating point. The deviation of the system frequency can be calculated from the power imbalance between supply and demand.

3.5 Modeling of Seawater Desalination Plant

Various characteristics such as mechanical properties or chemical properties should be considered for detailed modeling of seawater desalination plant. To simplify the model, it is expressed by a first-order lag model with a reference value of input power as an input and an actual input power as an output in this paper. Its time constant is 3sec. As the first step of this research, the influence of water demand and the constraint of the capacity of the storage tank are not considered.

4 PROPOSED CONTROL METHODS

In this paper, two new control methods of the seawater desalination plant for contribution of the power system operation are proposed.

4.1 Control for More Economic Generation Planning

In the proposed method, when the generation schedule is planned every 1 minute, the reference power consumption of the seawater desalination plant is determined based on the following two rules.

(A)When stop of the WTG is planned, the reference power consumption of the seawater desalination plant is increased so that stop of the WTG can be avoided. Fuel costs of DEGs strongly depend on the WTG operating time. The avoidance of WTG stop helps saving the DEGs operating time. Consequently, fuel costs can be reduced.

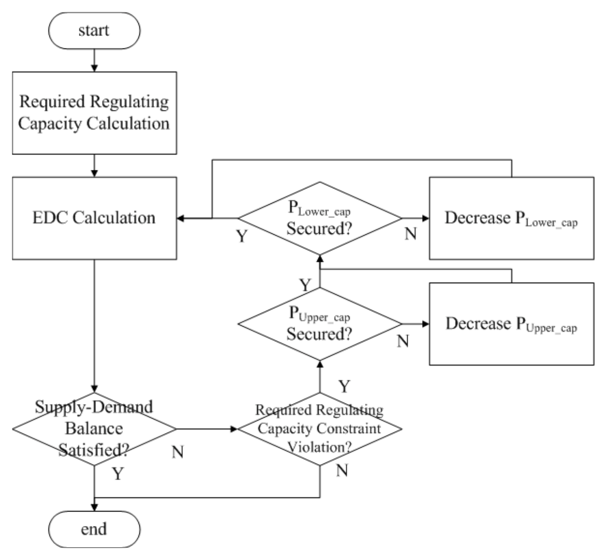


Figure 4: Flowchart of EDC calculation considering required regulating capacity constraint.

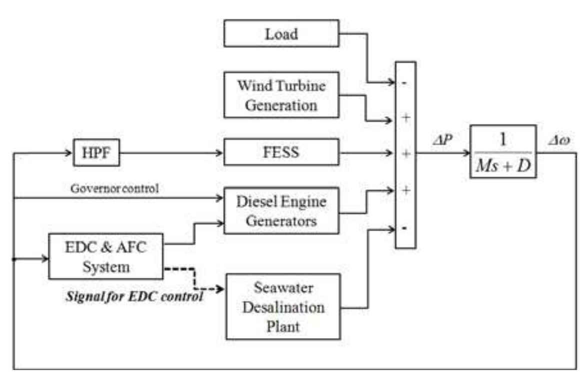


Figure 5: Frequency analysis model.

(B)When the shortage of the number of operational diesel engine generators occurs, the power consumption of the seawater desalination plant is decreased in order to keep the power balance between supply and demand without adding a new generator.

When a large amount of renewable energy based generation is installed into a small island power system, the On-Off state of each diesel engine generator will be changed very frequently to compensate for a large fluctuation of the renewable energy based generations. However, most of generating plants usually have minimum preparation time before startup. Consequently, the shortage of the number of operational diesel engine generators may occur as a result of their frequent On-Off operations in order to compensate for the power fluctuation only in the near future. The control for more economic generation planning aims at avoiding the frequent On-Off state change of diesel engine generators and the WTG and reducing the fuel costs.

The calculation method of the reference power consumption of the seawater desalination plant is as follows:

When the supply and demand power balance constraint cannot be held because of the shortage of the control margin of DEGs, the power imbalance between supply and demand is calculated. The reference of power consumption of the seawater desalination plant is determined in order to compensate this imbalance as much as possible as shown in Fig. 6.

4.2 *Control for More Required Regulating Capacity*

As already mentioned in the subsection 3.3, required regulating capacity may be decreased for holding supply and demand power balance constraint. In order to secure more regulating capacity, the power consumption of the seawater desalination plant is controlled by the following method shown in Fig. 7 when the required regulating capacity constraint violation is occurred.

If both constraints are not satisfied, P_{Lower_cap} and P_{Upper_cap} are both decreased. In this case, the reference power consumption of the seawater desalination plant is not changed. When only one constraint is violated and the seawater desalination plant has the controllable margin, its reference power consumption is changed slightly in order to hold required regulating capacity constraint. In this calculation, the total regulating capacity of all generators increases 1kW when the reference power consumption of seawater desalination plant is increased by 1kW. However, the total regulating capacity of quicker-response generators always does not increases 1kW because of EDC calculation. In order to secure the desired regulating capacity of quicker-response generators, the calculation shown in Fig. 7 is carried out with changing the reference power consumption of the seawater desalination plant step by step.

4.3 *Combined Control*

In the subsections 4.1 and 4.2, two control methods are proposed. The control for more economic generation planning aims at keeping the supply and demand power balance and reducing the fuel costs. On the other hand, the control for more regulating capacity aims compensating the short-term fluctuation effectively. Consequently, the combined control of two controls is proposed in order to obtain the both merits.

As for the combined control, the decision method of the power consumption of the seawater desalination plant is very important. In this paper, it is determined based on the following steps:

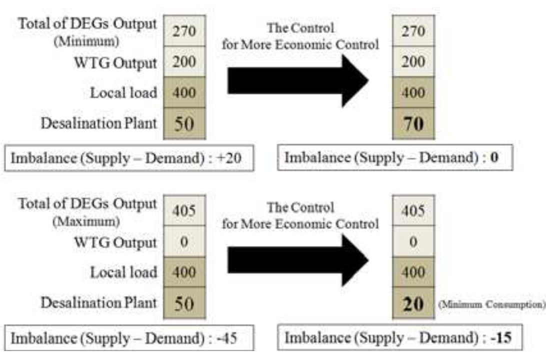


Figure 6: The Control for more economic generation planning.

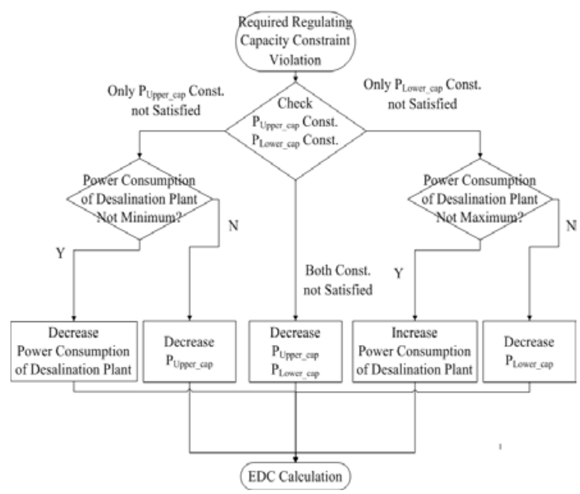


Figure 7: Flowchart of the control for more required regulating capacity.

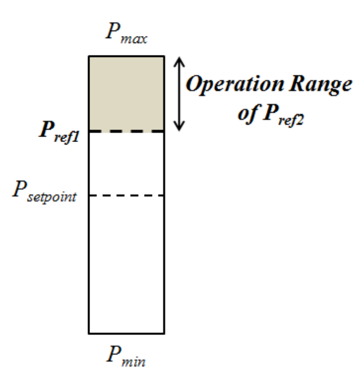


Figure 8: Decesion method of P_{ref2}.

To simplify the explanation of the combined control, the situation in which the power consumption of the seawater desalination plant must be increased is assumed. At first, the reference power consumption P_{ref1} is calculated based on the control for more economic generation planning. The value of P_{ref1} means that the power consumption of the seawater desalination plant must be more than P_{ref1} in order to keep the supply and demand power balance. Therefore, the reference power consumption P_{ref2} for the control of required regulating capacity must be between P_{ref1} and the maximum power consumption as shown in Fig. 8. Finally, the reference power consumption is determined as P_{ref2} after the calculation of the control for more required regulating capacity.

5 SIMULATION CONDITION AND RESULTS

5.1 Simulation Conditions

All simulations consider local load change shown in Fig. 9 and wind velocity change shown in Fig. 10. Simulation period is 24 hours from 0 o'clock.

5.2 Simulation Cases

Four simulation cases shown in Table 2 are considered in this paper.

5.3 Results

The frequency fluctuation, the power fluctuation and the diesel engine generator output during the simulation period in all cases are shown in Figs. 11 to 14.

Table 3 shows the staying rate of system frequency in all cases. At first, from the comparison with Case(1) and the other 3 cases, it is seen that seawater desalination plant can contribute the suppression of system frequency fluctuation. Especially, Case(3) and Case(4) have better results than Case(2). More regulating capacity of power system in Case(3) and Case(4) can be secured due to the control of the seawater desalination plant for more regulating capacity. For example, compared with Figs. 11(a) and 12(a) around 6 o'clock, it can be seen that system frequency reaches over 61Hz in Case(2) but suppresses under 60.5Hz in Case(3). In this period in Case(2), the total output of DEGs are almost minimum and the power consumption of seawater desalination plant is increased for the control of more economic generation planning, though this increase amount is a little and is not adequate for balancing supply and demand of the power system. In the more economic generation control, the power consumption of seawater desalination is changed based on only the power imbalance value calculated by EDC. Therefore it is hard to suppress the unpredictable short-term WTG output fluctuation. On the other hand, in the control for more regulating capacity, the power consumption of seawater desalination is changed based on the forecast of WTG output fluctuation. Therefore, the unpredictable short-term WTG output fluctuation can be suppressed.

Table 4 shows the fuel costs of diesel engine generators. As for the fuel costs, Case(2) and Case(4) are better results. About 2.5% of the fuel costs in Case(2) and Case(4) are reduced in comparison with Case(1). The fuel costs strongly depend on the operation of the WTG. For example, the WTG is not operated during 7 o'clock and 9 o'clock as shown in Fig. 11(b) due to the shortage of lower regulating capacity for low local load. 3 diesel engine generators are operated in this period as shown in Fig. 11(c). However, in Case(2), the WTG is operated during the most of this period. The lower regulating capacity can be secured by the increase of the power consumption of the seawater desalination plant. Figure 15 shows the partial enlarged figure of the power consumption of seawater desalination plant in Case(2). The stop of WTG during the 7 o'clock and 9 o'clock can be avoided for a little increase of the power consumption of the desalination plant as shown in the enclosed point by the oval of Fig. 15.

In these simulations, the control for more regulating capacity can help suppressing the system frequency fluctuation and the control, and the control for more economic control can reduce the fuel costs of diesel engine generators. Moreover, the combined control can bring the both advantages.

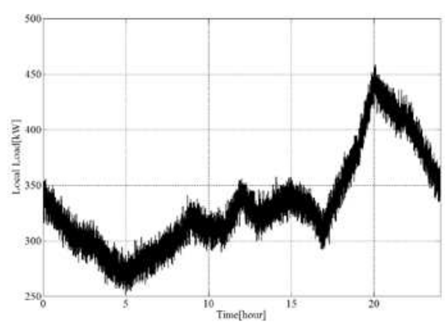


Figure 9: Load change(excluding seawater desalination plant).

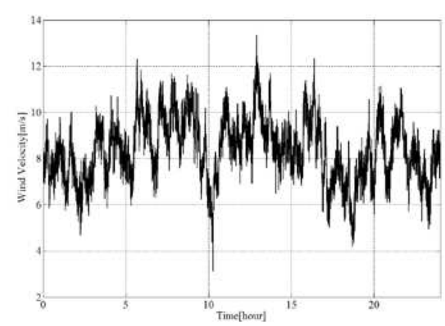
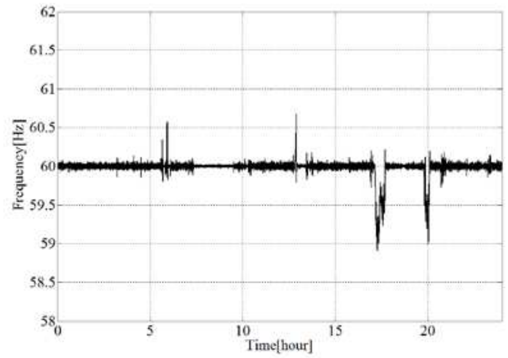


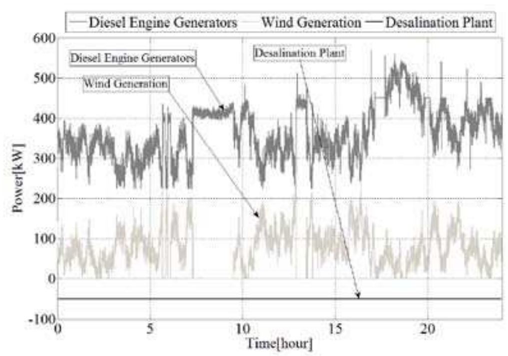
Figure 10: Wind velocity change.

Table 2: Simulation cases

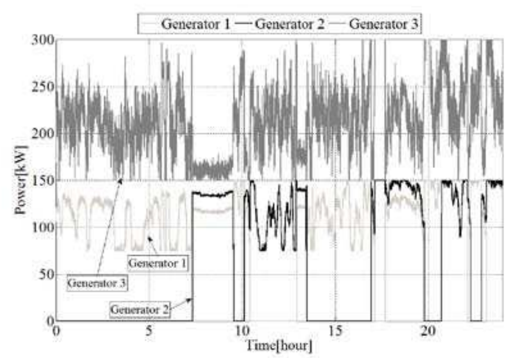
Case(1)	w/o the control of desalination plant
Case(2)	with the control of more economic generation planning
Case(3)	with the control for more regulating capacity
Case(4)	with the combined control



(a)Frequency fluctuation

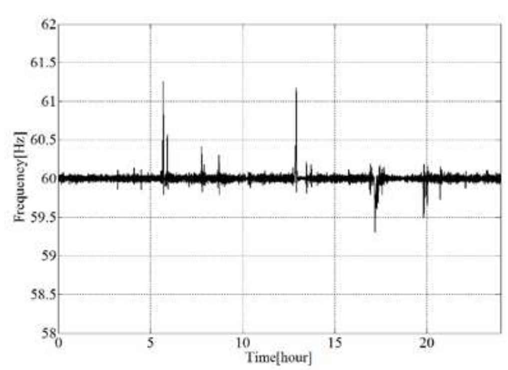


(b)Power fluctuation

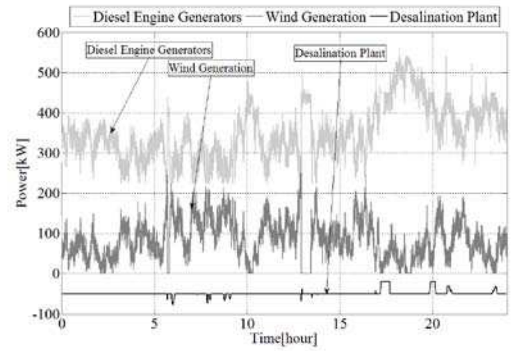


(c) Diesel engine generator output

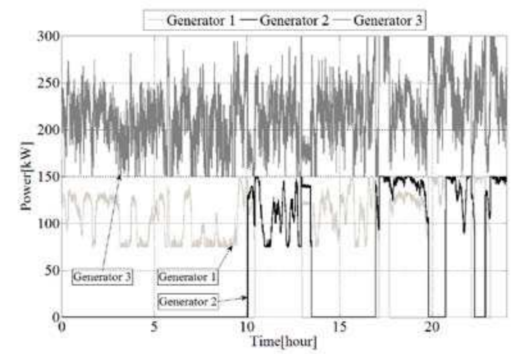
Figure 11: Simulation results (Case(1)).



(a)Frequency fluctuation

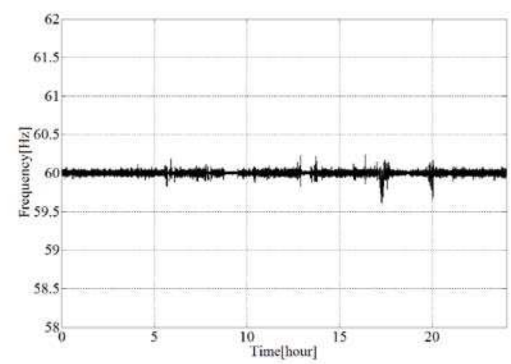


(b)Power fluctuation

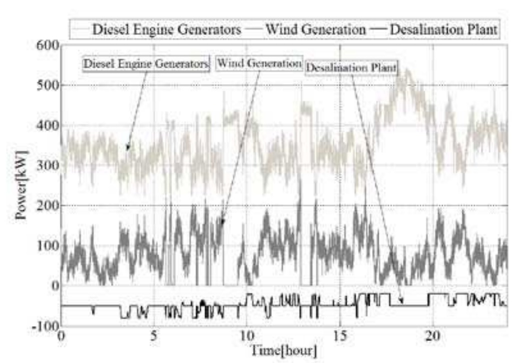


(c) Diesel engine generator output

Figure 12: Simulation results (Case(2)).

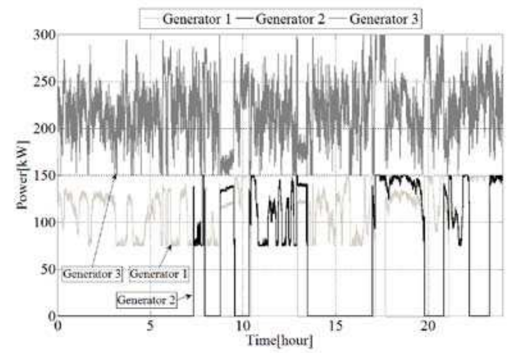


(a)Frequency fluctuation



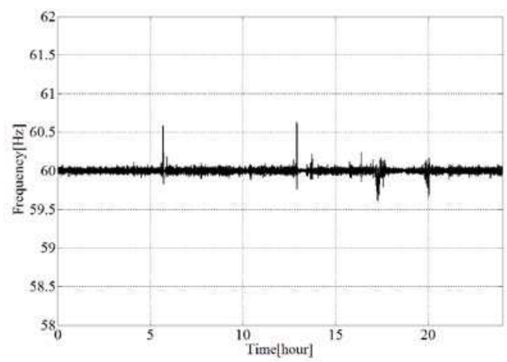
(b)Power fluctuation

Figure 13: Simulation results (Case(3)).

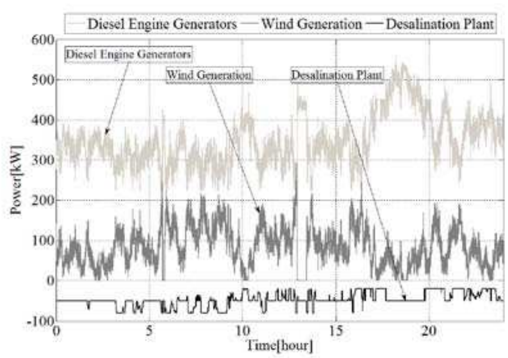


(c) Diesel engine generator output

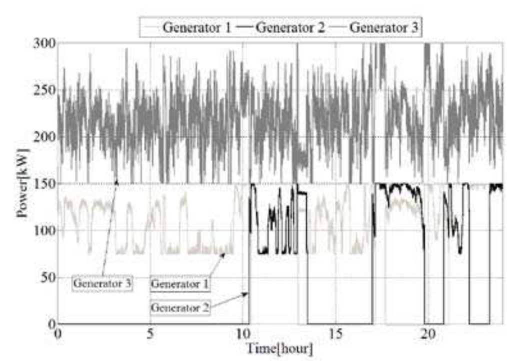
Figure 13: Simulation results (Case(3)).



(a)Frequency fluctuation



(b)Power fluctuation



(c) Diesel engine generator output

Figure 14: Simulation results (Case(4)).

Table 3: Staying rate of system frequency

	60±0.1[Hz]	60±0.2[Hz]	60±0.3[Hz]
Case(1)	95.37	96.29	96.78
Case(2)	97.12	98.47	99.08
Case(3)	**98.79**	**99.62**	**99.90**
Case(4)	**98.59**	**99.41**	**99.75**

Table 4: Fuel costs and operation time of WTG

	Fuel Costs [*10^5 JPY]	Operating Time of WTG[min]
Case(1)	4.764	1245
Case(2)	**4.645**	**1396**
Case(3)	4.698	1313
Case(4)	**4.637**	**1396**

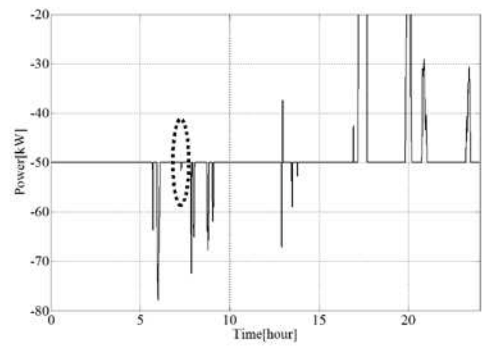


Figure 15: Enlarged figures of the power consumption of the desalination plant in Case(2).

6 CONCLUSION

In this paper, the two control schemes of the seawater desalination plant for power system operation are proposed. The control for more economic control has aimed at the reduction of fuel costs, and the control for more regulating capacity has aimed at suppression of the system frequency fluctuation. Consequently, it is shown through the simulations that the combined control is the best one because it has the merits of both control schemes.

In this simulation, the customer's convenience is not considered. For the operator of desalination system, the customer's convenience is that the fresh water can always be supplied to the resident. Moreover, its mechanical constraints on the desalination plant are not considered here, either. These constraints will be considered in this future work.

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