Decouple PID Control of Compact Binary Power Generation

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Abstract: A compact binary power generation using low-temperature difference thermal energy can be produce electric power by utilizing low temperature difference between hot water and cold water. In this study, a reduced transfer function model of whole transfer function model for the compact binary power generation pilot plant is constructed. A decouple PID control system is also designed to control the power generation pilot plant using a pseudo diagonalization, gershgorin bands, and multi-stage pre-compensators.

Keywords: power generation, renewable energy, evaporator, condenser, non-interacting, pre-compensator, PID

1 INTRODUCTION

A compact binary power generation is to convert thermal energy into electric power using temperature difference between heat and cooling source such as heat of hot springs, or waste heat of factories, and ocean thermal energy, which are enormous quantitatively. Thermal power plant that uses fossil fuels such as oil, coal, and natural gas, but the compact binary power generation is an environment-friendly and semi permanent energy source. In this respect, the compact binary power generation using renewable energy has been attracted. However, the temperature difference of compact binary power generation system is much lower than that of the other commercialized steam power plants. Furthermore, controlled variables and manipulated variables of the system interact on each other in general. If a control system is designed without consideration of such case, it is possible to make worse the control performance, because a control loop exerts harmful influence to other control loop through the interaction. For that reason, an appropriate control system is required to obtain the stable electric power.

In this paper, a reduced transfer function model of whole transfer function model is built for a power generation pilot plant and a decouple PID control system is designed to control the plant.

2 MODELING OF COMPACT BYNARY POWER GENERATION SYSTEM

2.1System structure and experiment Conditions

The block diagram of the power generation pilot plant by low- temperature difference is illustrated in Fig.1. The whole system consists of seven components: evaporator, condenser, separator, regenerator, turbine part (turbine and absorber), reducing valve, and working fluid pump.

1)Experimental conditions:

The pressure of the inlet and outlet of the turbine are measured by using amount of hot water as step input. At that time, Amount of cold water and working fluid is fixed. Next, amount of cold water is used as step input to measure the pressure of inlet and outlet of the turbine. At that time, amount of hot water and working fluid is fixed. The sampling time is 3[sec], the number of data is 100 samples.

A compact binary power generation system is modeled based on measured data.

2.2Transfer function models based on step response

The transfer function models for the compact binary power generation system using low-temperature difference are drawn by approximate methods using 1st time delay transfer function and 2nd order transfer functions is used to express oscillating component.

1) Transfer function model for evaporator

A block diagram of an evaporator is shown in Fig.2.The working fluid and hot water are used as input in the evaporator. The transfer function models of the evaporator are drawn as shown in Eq.(1)-(3).

$$G_{Ev}1(s) = \frac{1}{0.81s+1} \cdot \frac{15}{s^2+0.02s+15} \tag{1}$$

$$G_{Ev}2(s) = \frac{0.0875}{5s+1} \cdot \frac{15}{s^2+0.02s+15}e^{-s} \tag{2}$$

$$G_{Ev}3(s) = \frac{77.2}{1.1s+1} \cdot \frac{6}{s^2+0.07s+6}e^{-s} \tag{3}$$

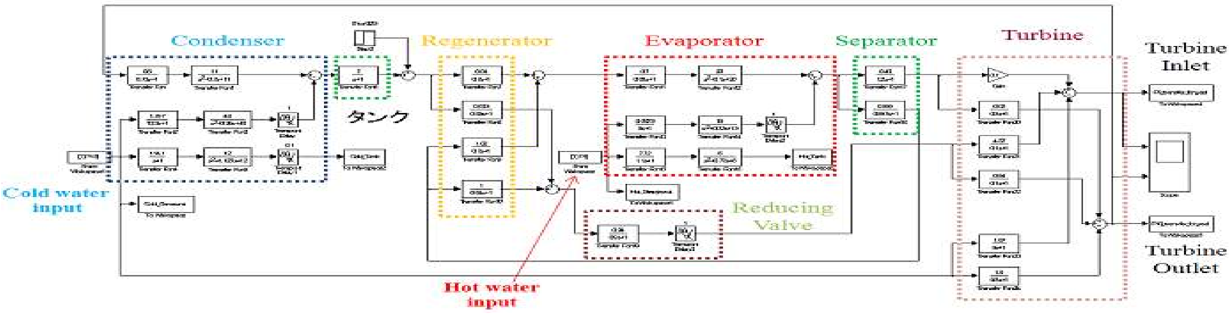

Fig.1. Block diagram of whole system

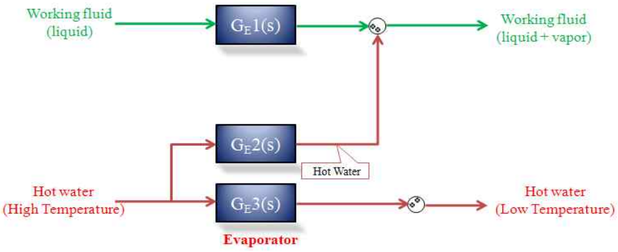

Fig.2. Block diagram of the Evaporator

In order to verify the transfer function models, the outputs from the evaporator of transfer function model are compared with the real data measured from the experimental plant. The simulation results are shown in Fig.3, Fig4respectively.

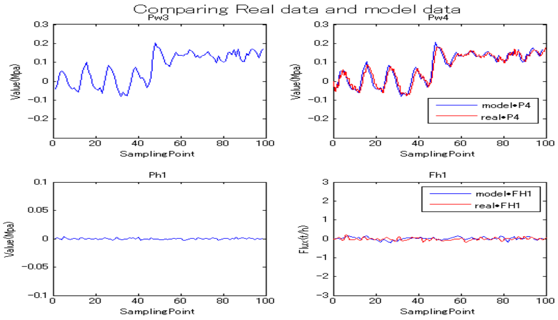

Fig.3. Input of working fluid, and outputs of hot water and working fluid for evaporator

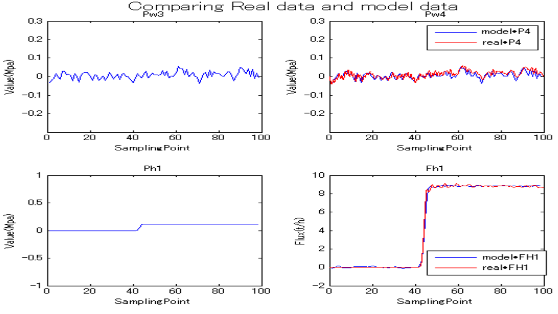

Fig.4. Input of hot water, and outputs of hot water and working fluid for evaporator

3) Transfer function models for additional components

A condenser, separator, regenerator, turbine part (turbine and absorb), reducing valve, and working fluid pump are modeled[1].

4) Deduction of total transfer function model for two inputs- two outputs system

For the total system, two inputs-two outputs transfer functions model that is regarded revolutions per minute of hot and cold water pump as manipulated values is modeled by using each of components of transfer function models. Fig.5 shows the block diagram of two inputs-two outputs transfer function model.

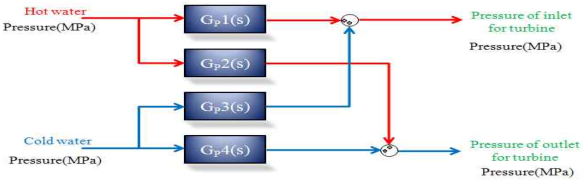

Fig.5. Transfer function model of two inputs two outputs

2.3Reduced order model

Obtained the transfer function models have a high order. In this paper, two inputs-two outputs transfer function model is represented as follows.

$$Gp11(s)=\frac{-0.002411\,s^3+0.004986\,s^2-0.003498\,s+0.001086}{s^4+0.6342\,s^3+0.3208\,s^2+0.05245\,s+0.002724}$$

$$Gp12(s)=\frac{0.1791\,s^3+0.08403\,s^2+0.02325\,s+0.004264}{s^4+0.4987\,s^3+0.2156\,s^2+0.02792\,s+0.00116}$$

$$Gp21(s)=\frac{-0.0005017\,s^3+0.001038\,s^2-0.0007492\,s+0.0002311}{s^4+0.6331\,s^3+0.319\,s^2+0.05208\,s+0.002703}$$

$$Gp22(s)=\frac{0.188\,s^3+0.07508\,s^2+0.02937\,s+0.001672}{s^4+0.4868\,s^3+0.2062\,s^2+0.02276\,s+0.0007496}\quad(4)$$

The simulation results of the reduced transfer functions are compared with transfer functions that are calculated by connection of the overall transfer functions as shown in Fig.6 and Fig.7, respectively.

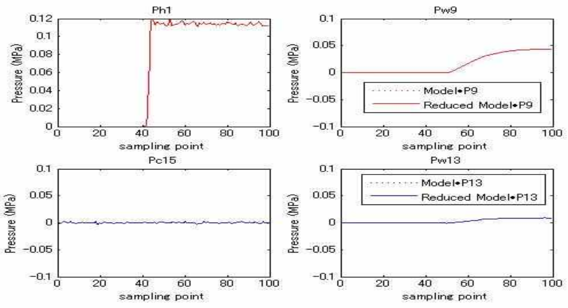

Fig.6. Input of cold water, outputs of working fluid, and cold water for condenser

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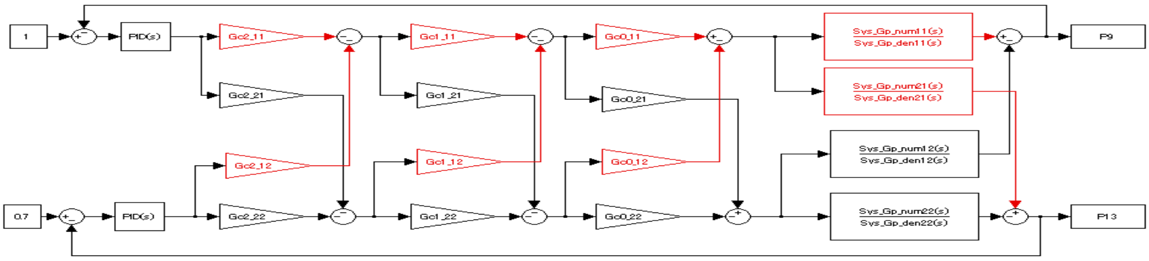

Fig.11. Block diagram of Decouple PID control system

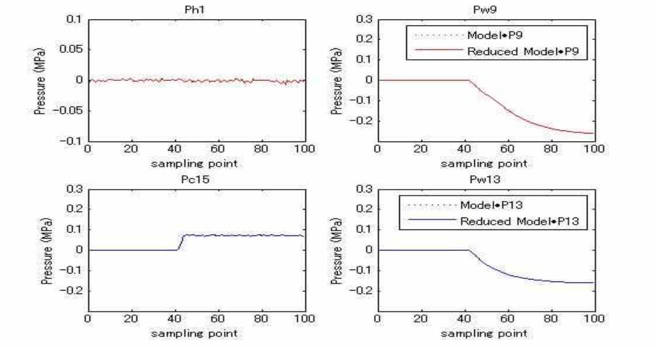

Fig.7. Input of cold water, outputs of working fluid, and cold water for condenser

3 MUlTI-STAGECONNECTED NON-INTERACTING PRE-COMPENSATOR

3.1Pre-compensator based on generalized pseudo digonalization method and diagonal dominance

For the transfer function matrix *Gp(s)*, if G_{c0} is expressed by Eq.(5), there is no interaction each other in frequency region at nearby $s=0$ from $G(0) = Gp(0)G_{c0}=I$[2].

$$G_{c0} = Gp(0)^{-1} = \begin{bmatrix} 3.8813 & -6.3958 \\ 0.1488 & -0.6936 \end{bmatrix} \tag{5}$$

The inverse nyquist array and the gershgorin bands of the system $G(s)=Gp(s)G_{c0}$ are shown in Fig.8.

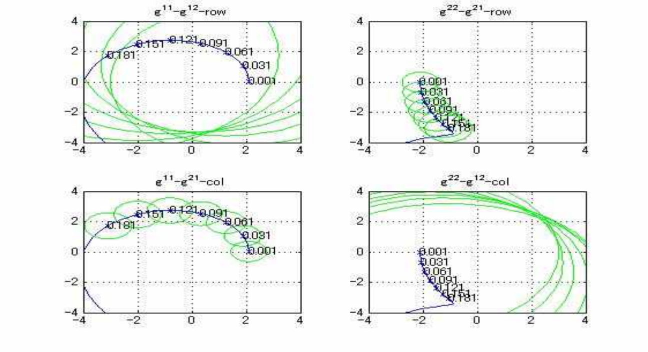

Fig.8. Inverse nyquist array, gershgorin band of $Gp(s)\ G_{c0}$

A pre-compensator $G_{c1}$is designed at w= 0.241 because the origin is included in a large number of gershgorin bands.

$$G_{c1} = \begin{bmatrix} -0.9998 & -0.9903 \\ -0.0222 & -0.1386 \end{bmatrix} \tag{6}$$

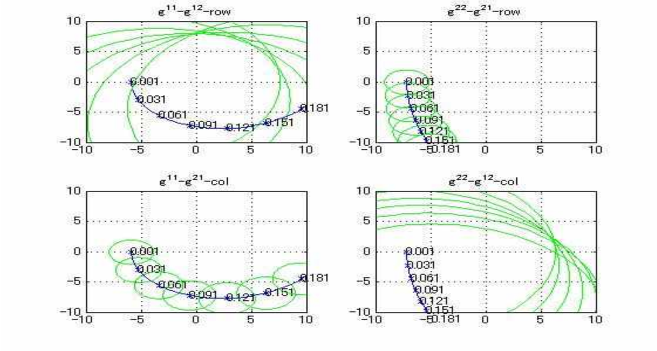

Fig.9. Inverse nyquist array and gershgorin bands by Gc_1

The origin is still included in the gershgorin bands as shown Fig.9 so that the multi-stage connection is considered [3].

3.2Multi-stage connection of Non-interacting pre-compensators

New pre-compensators G_{c1}, G_{c2} are designed to remove the interaction by using the multi-stage connection method and they are connected to three-stage series. Where G_{c1}, G_{c2} are designed at w= 0.241, w= 0.211, respectively.

The pre-compensators are calculated as

$$G_c(s) = G_{c0} \times G_{c1} \times G_{c2} = \begin{bmatrix} 2.9742 & -0.1376 \\ 0.0482 & -0.2590 \end{bmatrix} \tag{7}$$

The inverse nyquist array and the gershgorin bands are shown in Fig.10.

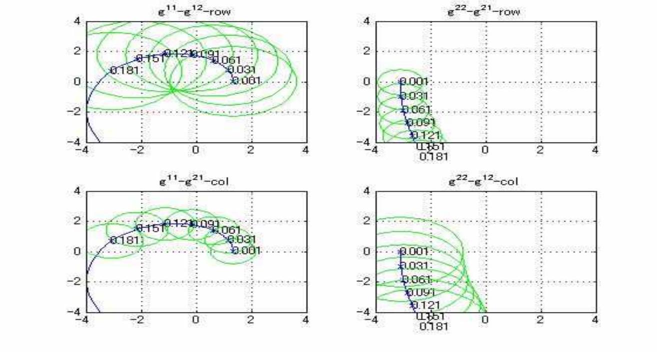

Fig.10. Inverse Nyquist array and Gershgorin band by $G_{c0}G_{c1}\ Gc_2$

The gershgorin bands do not include the origin any longer, so the diagonal column dominace is realized by 3-stage series connection.

4DESIGN OF DECOUPLE PID CONTROL SYSTEM

The goal of this control system is to design a controller to make the pressure difference between the inlet and outlet of turbine by 0.3[MPa]. The decouple PID control system of two inputs-two outputs system which controls the pressure at inlet-outlet for the turbine was designed by using pre-compensators as shown Fig.11.

4.1Design of PID control system

For the controlled system $G_p(s)$, PID parameters are designed by using the ultimate sensitivity method. The PID parameters and the result of PID control are shown in Table1and Fig.12, respectively.

Table1.PID Parameters

	Hot water pump	*Cold water pump*
K_p	5.136	-120
T_i	16.2	0.261
T_d	4.05	0.065

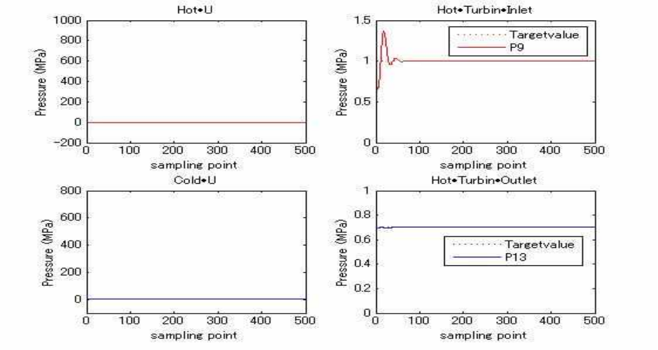

Fig.12. Result of PID control

4.2Design of Decouple PID control system

When the non-interacting pre-compensator *Gc* is used by three pre-compensator, the PID parameters of the decoupling control system are shown in Table2.

Table2.PID Parameters

	Hot water pump	*Cold water pump*
K_p	2.11	600
T_i	15.87	14.15
T_d	3.97	3.54

The modified PID parameters by trial and error and the result of the decoupling PID control system are shown in Table3 and Fig.13, respectively.

Table3.Modified PID Parameters

	Hot water pump	*Cold water pump*
K_p	0.0071	0.845
T_i	0.1914	22.54
T_d	1.3945	0.012

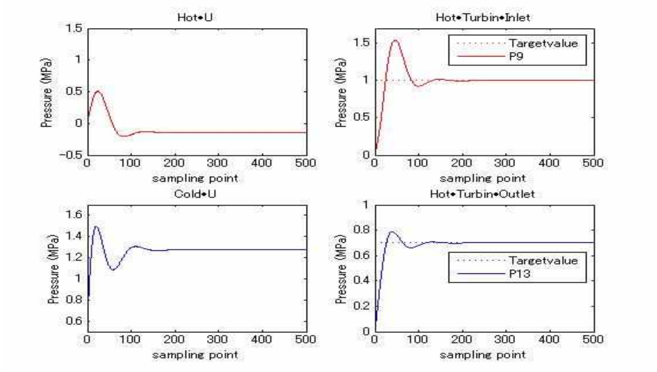

Fig.13. Result of decouple PID control

The control performance is improved by using 3-stage series connection of pre-compensators.

5CONCLUSION

The transfer function models of each of components for a compact binary power generation pilot plant using low-temperature difference thermal energy were built and they were integrated into the whole system. The reduced order transfer function model of two inputs-two outputs system which controls the pressure at inlet-outlet for the turbine was built, and the decoupling PID control system was designed. Also, the effectiveness of the transfer function models and the decoupling PID control system was confirmed through the simulation.

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