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Decouple Sliding Mode Control of Compact Binary Power Generation

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Abstract: This paper presents a Decouple Sliding Mode Control(DSMC) of a compact binary power generation using low-temperature difference thermal energy. First, a state equation model based on the transfer function model is deduced. Then, a Sliding Mode Control system with decoupler is designed to control the pressure difference between inlet and outlet of a turbine by high pressure steam of working fluid. The validity of the proposed model is confirmed by a comparison between simulation and experimental result and the control simulation results show the effectiveness of the decouple Sliding Mode Control**.**

Keywords: power generation, low temperature thermal energy, optimum servo system, decoupling control, sliding mode control(SMC), decoupling Sliding Mode control(DSMC)

1 INTRODUCTION

A compact binary power generation uses the temperature differential between hot and cold waters to produce electric power. In the closed cycle concept, a secondary working fluid(e.g., ammonia or Hydro-chlorofluoro-carbon) is vaporized and recondensed in a closed loop to drive a turbine. The working fluid is vaporized by hot water that is pumped by hot water pump and passed through heat exchangers. This working fluid expands, emerging as a high pressure steam which derives a turbine. The vapor is condensed by passing it through a second set of heat exchangers containing cold water pumped by cold water pump.

The compact binary power generation is an effective method of power generation, which has small impact on environment and can be semi-permanently utilized. Therefore, if the power generation using enormous thermal energy is commercialized it is expected that huge change can be brought to energy supply. However, compared with the thermal power generation using fossils or nuclear energy, whose temperature difference between heat source and cooling source is very low. Also, this kind of the system controlled variables and manipulated variables interact on each other in general.Therefore, for an efficiency and stable operation of the compact binary power generation plant, a robust control system that is suitable for the environmental factor or disturbance is required[1].

In our recent study, a transfer function model and a control system of the compact binary power generation was developed to control the pilot plant in frequency domain.This paper deals with a modeling and designing control system in time domain. A state equation model based on a transfer function model is developed and a Decouple Sliding Model Control system is also designed to control the pressure difference between the inlet and outlet of turbine to keep 0.3[Mpa] by the high pressure steam of working fluid. The simulation model is compared experimental data that measured from the compact binary power generation pilot plant and the control simulation results show the effectiveness of the DSMC.

2MODELING OF COMPACT BYNARY POWER GENERATION SYSTEM

The schematic diagram of the compact binary power generation pilot plant using low temperature difference thermal energy is illustrated in Fig.1. A feature of this pilot plant uses ammonia/water mixed working fluid.

2.1Experiment Conditions

- Hot water pump: 60[Hz], Cold water pump: 60[Hz], Working fluid pump: 70[Hz].
- Sampling period: 3 [sec], measured data: 100 samples.
- These data was measured under a steady sate of compact binary power generation pilot plant

2.2two inputs-two outputs system state equation model

In our previous study[2], the transfer function model is already drawn as shown Eq.(1). It was modeled by using approximated method using 1st and 2nd order time delay transfer function.

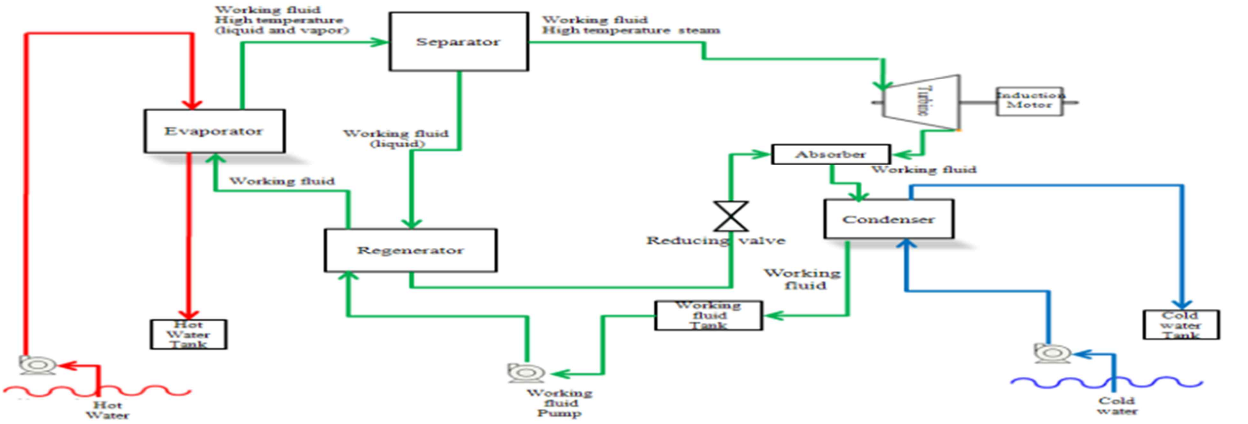

Fig.1. Schematic diagram of compact binary power generation system

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} \dfrac{0.0435}{5s^3+1.5s^2+5.1s+1}e^{-0.01s} & -\dfrac{1.6}{11s^3+1.99s^2+11.09s+1}e^{-s} \\ \dfrac{0.01}{9.8s^3+1.98s^2+1.08s+0.1}e^{-0.5s} & -\dfrac{1.9}{15s^3+1.15s^2+15.01s+1}e^{-s} \end{bmatrix} \begin{bmatrix} u_h \\ u_c \end{bmatrix} \tag{1}$$

Where, y_1,y_2 are the pressure of inlet and outlet of turbine and u_h,u_c are the manipulated value of hot and cold water respectively. In this paper, a state equation model based on two inputs-two outputs transfer function model is drawn by using matlab as shown in Eq(2).

The simulation results of the state equation model are compared as shown in Fig.3, Fig.4, respectively.

$$A = \begin{bmatrix} -0.463 & -1.2481 & 0.3076 \\ 0.9677 & 0.4546 & 0.0315 \\ -0.0095 & -0.0012 & -0.0639 \end{bmatrix}, \quad B = \begin{bmatrix} -0.0009 & -0.3899 \\ 0.0025 & 0.1181 \\ 0.0081 & -0.1584 \end{bmatrix}$$

$$C = \begin{bmatrix} -0.0713 & -0.0655 & 0.7009 \\ -0.3024 & -0.2924 & 0.8361 \end{bmatrix}, \quad D = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \tag{2}$$

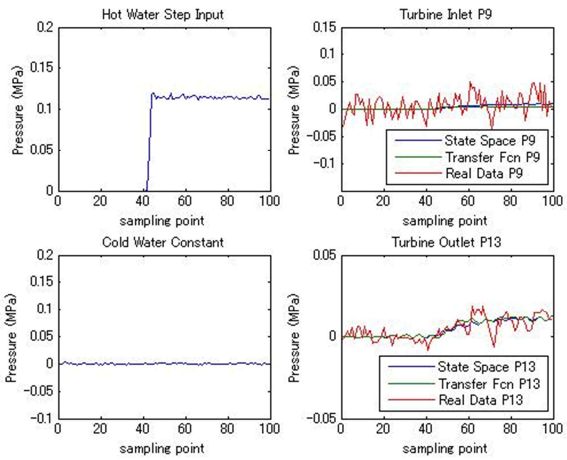

Fig.2. Input of hot water, outputs of inlet of turbine

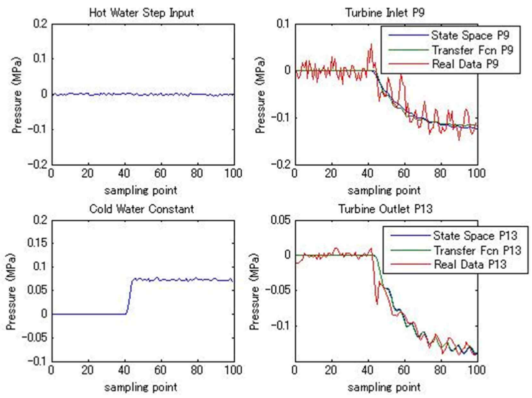

Fig.3. Input of cold water, outputs of inlet of turbine

3DECOUPLE SLIDING MODE CONTROL

Sliding Mode control is a robust control scheme based on the concept of changing with structures states of the system in order to obtain a desired response[3]. The biggest advantage of SMC is its robustness to variation in parameters, external disturbance and modeling errors, therefore, SMC with a decoupler is designed in this study.

3.1EquivalentControlSystem&Switching Hyper PlaneDesign

Let us consider as follows system,

$$\frac{d}{dt}\mathbf{x}(t) = (\mathbf{A} - \mathbf{B}\,\mathbf{F})\,\mathbf{x}(t) + \mathbf{B}\,\mathbf{G}\,\mathbf{u}(t)) \qquad \mathbf{y}(t) = \mathbf{C}\,\mathbf{x}(t) \tag{3}$$

where, $\mathbf{x} \in R^3, \mathbf{u} \in R^2, \mathbf{y} \in R^2$

The error and switching hyper plane is defined as Eq.(4).

$$\mathbf{e}(t) \equiv \mathbf{r}(t) - \mathbf{y}(t) \qquad \boldsymbol{\psi}_1 \equiv S_1\mathbf{e} + S_2\int \mathbf{e}dt \tag{4}$$

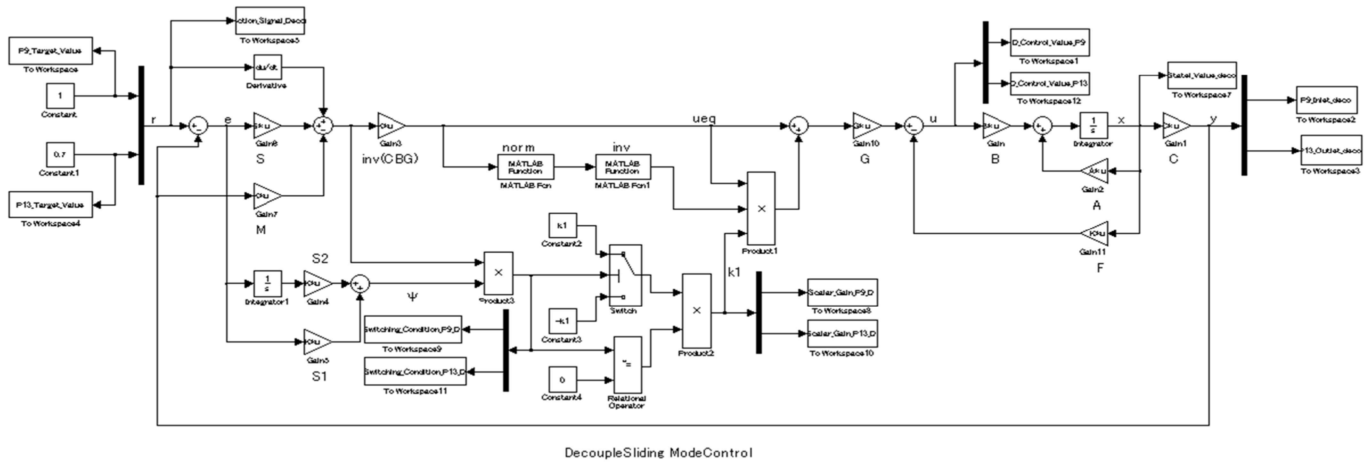

Fig.4. Block diagram of DSMC

When the state is restricted on a hyperplane, the equivalent control input U_{eq} can be obtained by Eq.(5) when $|S_1| \neq 0$,

$$\mathbf{CBGu}_{eq} = S_1^{-1} S_2 \mathbf{e} + \dot{\mathbf{r}}(\mathbf{A} - \mathbf{BF})\mathbf{x} \tag{5}$$

Also, the equivalent control input is obtained by Eq.(6) when *CBG* is nonsingular matrix.

$$\mathbf{u}_{eq} = (\mathbf{CBG})^{-1}(S_1^{-1} S_2 \mathbf{e} + \dot{\mathbf{r}} - \mathbf{My}) \quad (\mathbf{r} = \mathbf{m}) \tag{6}$$

Where, *M* satisfy,

$$\mathbf{C}(\mathbf{A} - \mathbf{BF}) = \mathbf{MC} \tag{7}$$

Eq.(7) may be rearranged as Eq.(8) by multiplying the transpose matrix of *C*.

$$\mathbf{M} = \mathbf{C}(\mathbf{A} - \mathbf{BF})\mathbf{C}'(\mathbf{CC}')^{-1} \tag{8}$$

In this paper, matrix *M* is obtained as Eq.(9).

$$\mathbf{M} = \begin{bmatrix} 0.2194\times10^{-16} & 0.4922\times10^{-16} \\ 0.1935\times10^{-16} & 0.1332\times10^{-16} \end{bmatrix} \tag{9}$$

Substituting for U_{eq} from Eq.(6) into Eq.(4) gives

$$\dot{\mathbf{e}} = \quad S_1^{-1} S_2 \mathbf{e} \tag{10}$$

where, let $S_1 = I, S_2 = S$, then

$$\dot{\mathbf{e}} = \quad - S\mathbf{e} \tag{11}$$

A Switching matrix *S* can be designed by setting an arbitrary eigenvalues.

3.2Sliding Mode Controller Design

Sliding mode controller is designed by using eventually hierarchy control law for the state of system to reach to switching hyper plane from arbitrary initial state x_0.

Let us define the Lyapunov function **V** with respect to Ψ_1 as Eq.(12),

$$\mathbf{V} \equiv \frac{1}{2}\boldsymbol{\psi}_1^T \boldsymbol{\psi}_1 \tag{12}$$

the condition of derivative time $\dot{\mathbf{V}}$ of the **V** is then given by Eq.(13),

$$\dot{\mathbf{V}} < 0 \tag{13}$$

This condition result in $\boldsymbol{\Psi}_1$ belong to the switching hyper plane.
Derivative time $\dot{\mathbf{V}}$ is rewritten as Eq.(14),

$$\dot{\mathbf{V}} = \boldsymbol{\psi}_1^T \dot{\boldsymbol{\Psi}}_1 = \boldsymbol{\Psi}_1^t (S\mathbf{e} + \dot{\mathbf{r}} - \mathbf{My}) - \boldsymbol{\Psi}_1^T \mathbf{CBu} \tag{14}$$

where, eventually hierarchy control input *u*, the equivalent control input as a linear control term, the unit input as a nonlinear control input and $k_1$as scalar gain is defined as Eq.(15),

$$\mathbf{u} \equiv \mathbf{u}_{eq} + k_1 \frac{\mathbf{u}_{eq}}{\|\mathbf{u}_{eq}\|} \tag{15}$$

where, $\|\bullet\|$ is norm.
Substituting Eq.(15) into Eq.(14), $\dot{\mathbf{V}}$ is rewritten as Eq.(16),

$$\begin{aligned} \dot{\mathbf{V}} &= \boldsymbol{\psi}_1^T (S\mathbf{e} + \dot{\mathbf{r}} - \mathbf{My}) - \boldsymbol{\psi}_1^T \mathbf{CBG}(\mathbf{U}_{eq} + k_1 \frac{\mathbf{u}_{eq}}{\|\mathbf{u}_{eq}\|} \\ &= k_1 \frac{\boldsymbol{\Psi}_1^T \mathbf{CBGu}_{eq}}{\|\mathbf{u}_{eq}\|} \end{aligned} \tag{16}$$

Hence, the switching condition scalar gain k_1 is obtained as Eq.(17).

$$k_1 \begin{smallmatrix}\le \\ >\end{smallmatrix} 0 : \quad if\ \mathbf{\Psi}_1^T \mathbf{CBGu}_{eq} \begin{smallmatrix}\le \\ >\end{smallmatrix} 0 \qquad (17)$$

3.3DSMC Control Simulation Result

A simulation is carried out using MATALB to verify the performance of the designed DSMC as shown in Fig.4.The results of DSMC are compared with SMC. In this paper, S_2, K_1 is configured 1000, 0.01 respectively. The goal of this control system is to make maintain the pressure difference between the inlet and outlet of turbine by 0.3[Mpa].

Fig.5 shows the comparative result of outputs.

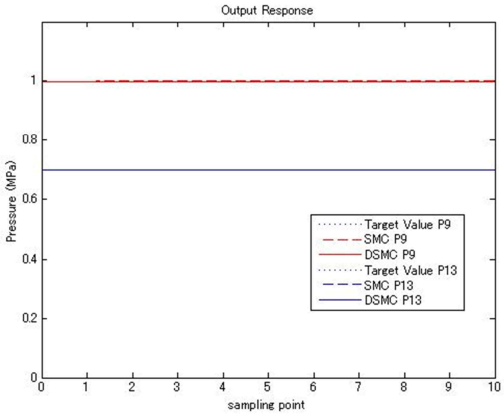

Fig.5. The result of outputs

Fig.6 shows the comparative result of control value.

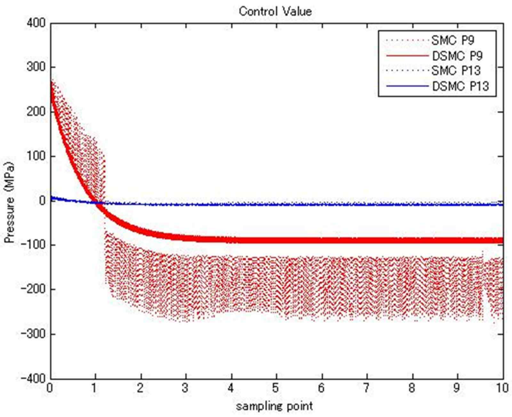

Fig.6. The result of control value

Fig.7 shows the comparative result of switching conditions.

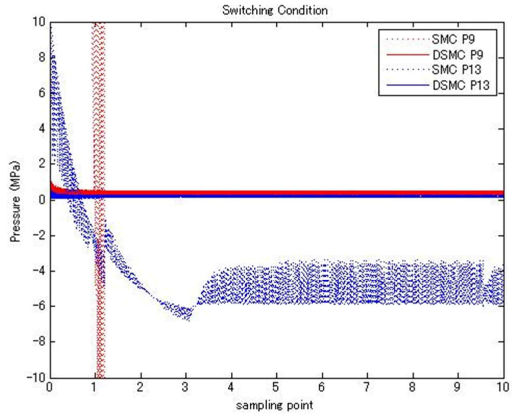

Fig.7. The result of switching condition

Fig.8 shows the comparative result of outputs of k_1.

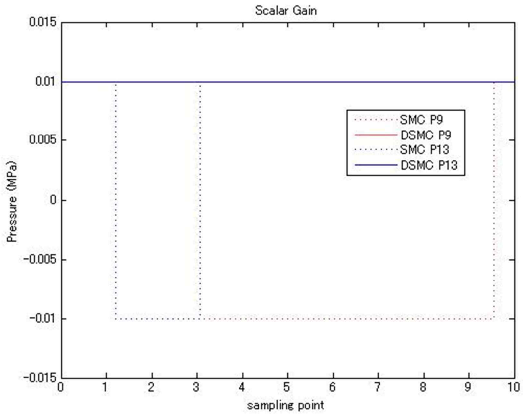

Fig.8. The result of k_1

4CONCLUSION

The state equation for two inputs-two outputs for a compact power generation pilot plant using low temperature difference is drawn. DSMC is designed to control the pressure at inlet-outlet of the turbine.

Also, the validity of the state equation model and the effectiveness of decoupler are confirmed through the simulation.

REFERENCES

[1] Kun-Young Han,Hee-Hyol Lee, "Neuro PID control of power generation using a low temperature gap", Artificial Life and Robotics, Vol.16.No.2,pp.178-184,2011.

[2] K-YHan, ARITAM,H-HLee,"Decoupling PID control System for Power Generation by Low-Temperature Difference", International conference on Humanized systems,pp.306-311,2012.

[3] H-HLee, SHOJI.F, TSURUOKAH, MIYAZAKI M, AKIZUKI K,"Frequency-ShapedSliding Mode Control Using Output Feedback and Application to Follow-up Control of Process System" ,SICE, vol.38,no.2, pp.186-192,2002.