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Model Predictive Control Based on System Re-Identification (MPC-SRI) to Control Bio-H_2 Production from Biomass

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Abstract. Compressors and a steam reformer are the important units in biohydrogen from biomass plant. The compressors are useful for achieving high-pressure operating conditions while the steam reformer is the main process to produce H_2 gas. To control them, in this research used a model predictive control (MPC) expected to have better controller performance than conventional controllers. Because of the explicit model empowerment in MPC, obtaining a better model is the main objective before employing MPC. The common way to get the empirical model is through the identification system, so that obtained a first-order plus dead-time (FOPDT) model. This study has already improved that way since used the system re-identification (SRI) based on closed loop mode. Based on this method the results of the compressor pressure control and temperature control of steam reformer were that MPC based on system re-identification (MPC-SRI) has better performance than MPC without system re-identification (MPCWSRI) and the proportional-integral (PI) controller, by % improvement of 73% against MPCWSRI and 75% against the PI controller.

1. Introduction

A biohydrogen from biomass process consists of raw material processing unit, gasification unit, char decomposer unit, compression unit, steam reforming, char combustors units, unit coolers, H_2S removal units, and pressure swing absorber unit. Among these processes, the compression and the steam reformer units are the very important units in generating biohydrogen effectively since they influence the subsequent performance of the units and will determine the amount of the next product. Compression unit tasked to raise the pressure coming out of the gasification unit in order to reach high pressure to operate. The high pressure needed for H_2S removal operation conditions. This material has been eliminated, because it contains toxic substance that can be harmful for humankind.

In order to achieve an optimal condition for the operation of the plant, it is necessary to use a controller on the units. Therefore, if there is any kind of disturbance outside, it can be rejected to maintain the stability for the operation of the plant. Research on controling these units have been carried out [1] using the PI controllers. This research used a MPC which is one of the advanced control. The MPC is a model-based control and a multi variable control [2-3]. Therefore, the application of MPC controllers is expected to be better than the PI controller. To develop a plant model, this research employs a process simulator [4-5]. Since the factors which influenced the MPC is the used of the model, so the best models of the systems need to find out. In this case, we used a new approach called the system re-identifications [6]. System re-identification turns commonly used in image processing world [7-8].

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2. Methodology

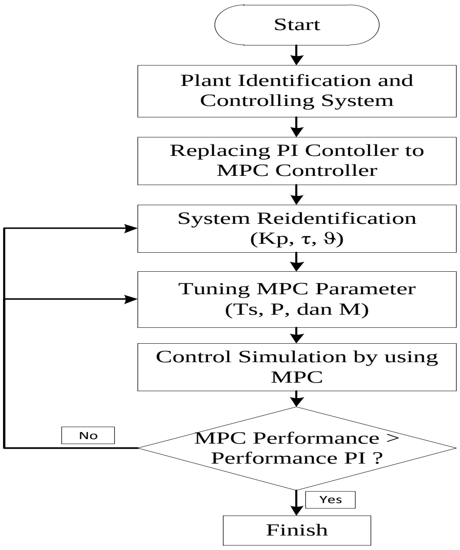

Figure 1 Flowchart of the research

2.1 Flowchart of the Research

The methodology of this research outline consists of several steps. These steps can be done through performing a simulation using the software for process simulation. Flowchart of research methods can be seen in Fig. 1. This research used a process simulator (UniSim$^{(R)}$) operated in dynamic mode [5]. While the plant used is the result of the pre-design [9].

2.2 Simulation Study

Figure 2 shows the control system of compressor and steam reformer at the bio-hydrogen from biomass plant, which consists of four pressure controls and two temperature controls. Because of the compressor used is a centifugal type, each compressor must be equipped with anti-surge control to avoid the surge (back flow) due to the inlet flow rate to compressors below the surge limit.

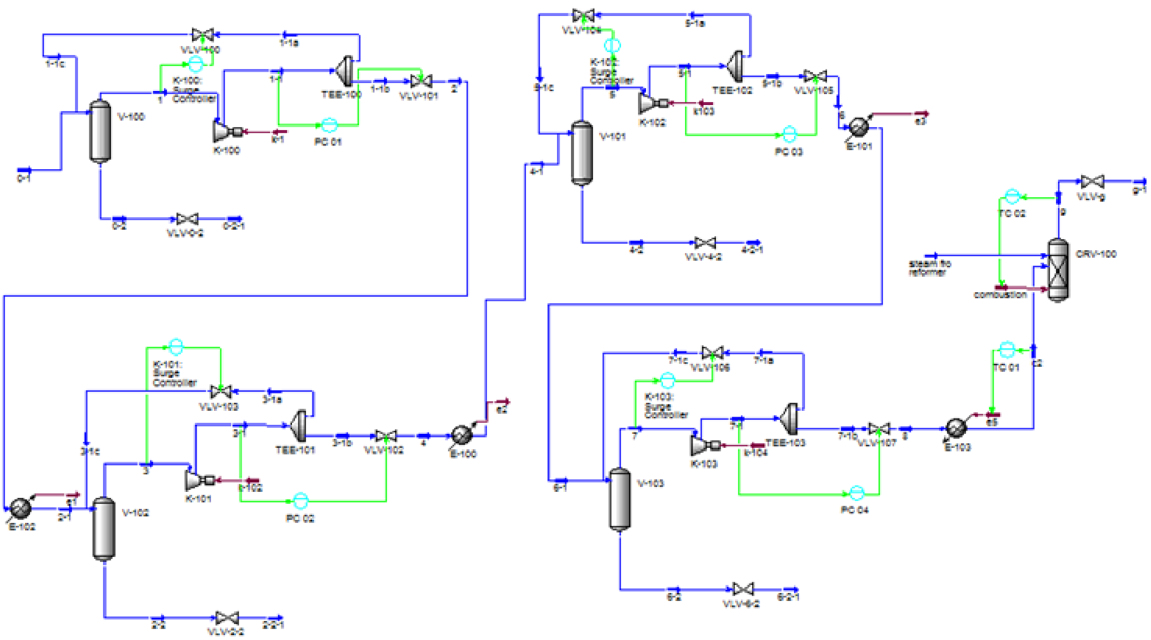

Figure 2 Compressor and steam reformer controls using UniSim$^{(R)}$

Table 1 shows the controlled variables (CV), process variable source, and output target or manipulated variables (MV). When using PI controller, the closed mode system identification carried out by model testing. The system will be given set point change so that it can obtain empirical models of FOPDT using the method II [10-11]. MPC using the FOPDT parameters: K_p (process gain), θ (dead-time), and τ (time constant), directly in the control. The FOPDT model is expressed in transfer function equation as follows:

$$G(s) = \frac{K_p e^{-\theta s}}{\tau s + 1} \tag{1}$$

where G(s) is transfer function, and s is Laplace Transform variable (complex number).

Table 1 Controlled Process Variable

Unit	Controlled Variable	Process Variable Source	Output Target
Compressor	Stream Pressure that will come to H2S Removal unit	Capacity Control : motor speed	Capacity Control : Control valve
Steam Reformer	Inlet Stream Temperature of Steam Reformer	Heat of Heat Exchanger after Compressor Unit	Control Valve
	Outlet Stream Temperature of Steam Reformer	Combustion of Steam Reformer	Control Valve

Empirical model parameters obtained from model testing at PI controller is the initial model of a system. This model will be identified back to get a new model. If the new model has a control performance better than the early models, the integral of absolute error (IAE) as a measure of performance, it will be re-identification to get IAE worse (larger) than before, which means that it is the limit of re-identification. The last model which has the smallest IAE is the best model to be used in the MPC with system re-identification (MPC-SRI), while the MPC without system re-identification (MPCWSRI) used as the comparison, beside the PI controller [12]. To tune the MPC parameters (sampling time, T, prediction horizon, P, and control horizon, M) used the Dogherty-Cooper method [13].

3. Results and Discussion

3.1 System Re-Identification using MPC

Modeling the MPC controller is done through the same way with the PI controllers with each controller setpoint change to see the change of reaction generated by the controller to achieve stability. In this research, there are 4 compressors and 1 steam reformer. In a steam reformer there are 2 pieces of control (heater temperature control and combustor temperature control). Thus, in this study there are 4 pressure controllers and 2 temperature controllers. To control the pressure in the compressor unit, the setpoint will be changed by +7 and -7 kPa, while the temperature control for steam reformer unit will be changing the setpoint of +10^{o}C and-10^{o}C. Each controller is done changing the setpoint until it reaches the lowest IAE. It is aimed to obtain the maximum and the precise models. The parameters model obtained will be continued to the modification of MPC (T, P and M).

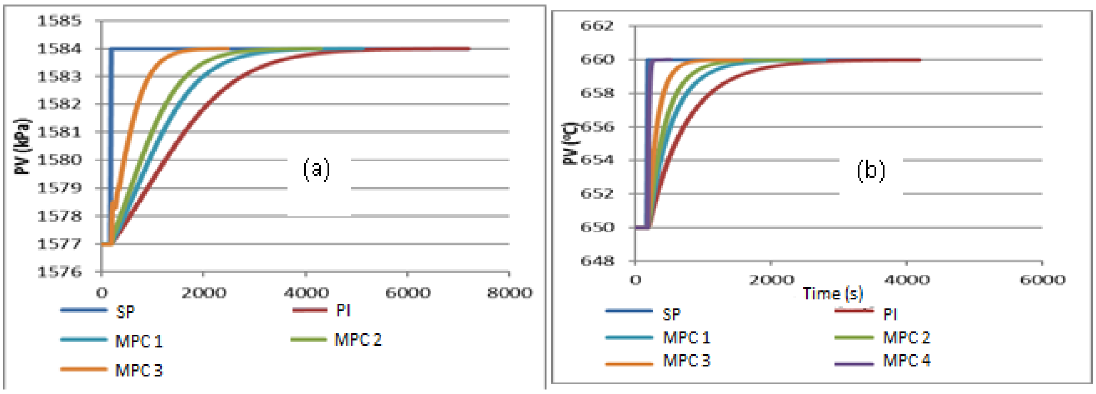

Figure 3 PRC of (a) Pressure Control in compressor, (b) Temperature Control of heater unit in Steam Reformer

In reidentifying the system we will calculate the empirical value of the system, the value of empirical can be seen from Figure 3. The results of this modeling will be used to see the response of the controller when disorders given. The result of modeling the latter on each unit is the best models, so that it will do the adjustment. Model Testing performed to obtain the minimum IAE values for each controller to get more accurate results. Results of tuning on each controller can be seen in Table 2, where PC1 – PC4 are the pressure controls of the compressor 1 – 4 and M1 – M4 are models result from the re-identifications. Table 3 shows the results of tuning in temperature control of heater and combustor.

From modeling conducted on each controller, the modeling results are used to do further adjustment MPC which is modeling the latter. The results of the empirical best setting for each controller are appreared in Table 4.

Table 2 Tuning of PC in compressors

FOPDT	PC1				PC2				PC3			PC4	
	M1	M2	M3	M4	M1	M2	M3	M4	M1	M2	M3	M1	M2
K_p	-0,65	-0,51	-0,23	-0,15	-0,71	-0,57	-0,30	-0,16	-0,42	-0,28	-0,70	-0,70	-0,70
τ	0,50	3,42	7,25	6,26	16,93	29,08	42,83	6,97	29,31	23,42	1,56	5,25	1,00
θ	1,30	0,30	1,52	1,09	2,31	8,04	9,40	1,27	5,07	7,09	0,82	0,09	1,17

Table 3 Tuning of TC in the heater and combustor

	TC1				TC2
	M1	M2	M3	M4	M1
K_p	0,22	0,22	0,60	3,40	0,31
τ	36,00	9,48	3,50	0,51	2,00
θ	0,33	0,52	0,67	0,33	0,17

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Table 4 Result of FOPDT PRC of each Control

No.	Controller	Kp	τp	ϴ
1	PC 1	-0,15	6,26	1,09
2	PC 2	-0,16	6,97	1,27
3	PC 3	-0,70	1,56	0,82
4	PC 4	-0,70	1,00	1,17
5	TC 1	3,40	0,51	0,33
6	TC 2	0,31	2,00	0,17

3.2 MPC Controller Performance

The results of the PI controller tuning compressor units - 3 were setup using Ziegler Nichols method, where the best results obtained with a value of Kc = 0.7187 and Ti = 0.3556. As for the MPC controller, empirical values used are Kp = -0.7006, τp = 1.5563, and θ = 0.8168, parameter value adjustment for fine tuning the MPC outcome of this unit is

Step Respon Length (SRL) = 50
Prediction Horizon (P) = 50
Control Horizon (M) = 3
Control Interval (Ts) = 2

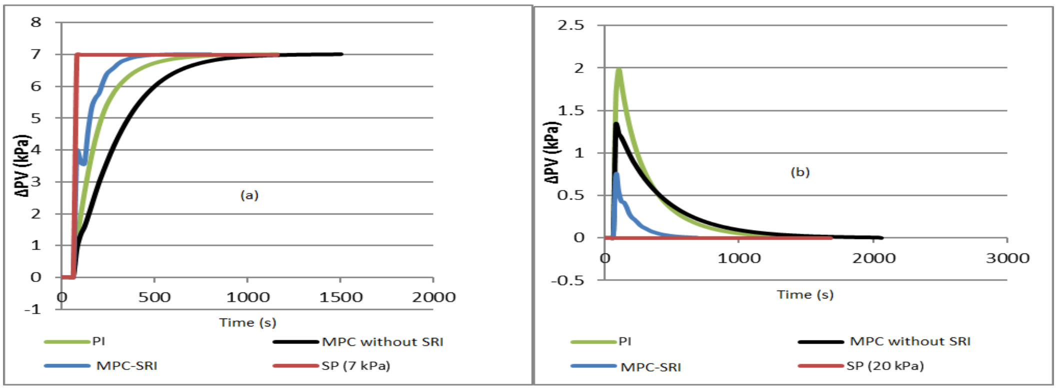

Figure 4 PV Responses of MPC and PI in Compressor Unit-3 at (a) setpoint of +7 kPa and (b) disturbance in inlet pressure of 20 kPa

Based on Figure 4 (a), it can be seen that after the MPC controller modeled is able to provide a faster response than the PI controller to change the setpoint of 7 kPa, which proves that the MPC controller is better than PI controller. Therefore, when compared to the MPCWSRI, which has the performance of MPC-SRI is better than the performance of the MPCWSRI. It proves that the system re-identification will give a more optimal models result.

Figure 4 (b) shows the response of the compressor-3 unit controller when a 20 kPa pressure disturbance input given. The blue graph is the result of MPC response which shows a better performance than the PI controller performance results. Both controllers managed to control the system, but MPC to control and restore the initial conditions more quickly than the PI controller. Therefore, when compared to the results of the MPC performance without Re-identification it comes to a proof that the MPC needs to be re-identified first.

Thus, based on both of these pictures it can be calculated from the value of the parameter controlling the success of each method to be compared quantitatively. The results of the calculations are presented in Table 5.

Table 5 The Result of Performance of Control in Compressor Unit-3

Parameter	PI	MPC	MPC without Reidentification
Offset	0	0	0
Rise Time (s)	1160	801	1500
Peak Time	0	0	0
Overshoot	0	0	0
Settling Time (s)	780	440	1090
Decay Ratio	0	0	0
Period	0	0	0
Maximum Deviation	0	0	0
IAE	42	20	76
ISE	129	47	264

Ten parameters are tested on Compressor Unit-3 shows that the performance of the MPC controller is much better than the PI controller. PI controller requires a longer time to reach a steady state. Similar results were also obtained from the MPC without Re-identification which requires a longer time to reach a steady state.

The same thing will be generated in Compressor Unit 1, Compressor Unit 2, Compressor Unit 4, Unit Heater and Combustor in the Steam Reformer. Each MPC controller produces better performance than the performance of PI controller. MPC has proved its ability in controlling the pressure and the temperature. MPC tuning parameters in this research performed using a non-adaptive adjustment based on calculations developed by Dougherty Cooper [13] and used the method of fine tuning also [14-16]. Tuning results using a non-adaptive method showed no response to setpoint changes given to the controller. This suggests that the non-adaptive MPC controller cannot function properly. As for the result of fine tuning the MPC controller shows a very maximum result. it is an evidence from the comparison between MPC controller and PI controller are very significant. Therefore, the fine tuning method used is very precise.

Non-adaptive MPC showed no changes can be caused by the range of prediction horizon (P) is too big, based on the calculations in which the process of this system does not require high P. In addition, the control interval (T) required by the results of the calculation are also quite large, whereas in doing the fine tuning control method which takes the value of T is small enough to obtain optimum results. Otherwise, if it is done through the sufficiently high control interval, then the process becomes quickly unstable or excessive response to the setpoint influence itself. Thus, the adjustment using a non-adaptive method is not recommended for use in MPC. MPC is a control that can optimize a control. The downside of this is that if the MPC is given a high interference, the response will be very bad then it tends to be unstable and always does the oscillations. Unlike the PI controller, it is capable of controlling a given system even though the disturbance is high. MPC will perform much better than the PI when a small disturbance given, but does not apply if the MPC is given a high interference, then the MPC will tend to be unstable. Hence, the model is referred to as the controller of MPC works for optimization.

Based on the above research, a measurable percentage increases in performance of MPC after the modeling and the tuning. Results improved performance of MPC can be seen in Table 6. Table 6 shows that the performance of MPC is much better than the performance of the PI controller by % improvement of 75%. This means that the modeling which done is very useful to increase the performance of a controller. This can be seen when the MPC controller does not do the re-identification in this research used the empirical model, the MPC controller performance will not be better and tend to be bad, that is why it is very necessary to do the re-identification.

Table 6 Improvement for each control performance

Controller	IAE PI	IAE MPC-SRI	IAE MPC Without Reidentification	% Improvement (To MPCWSRI)	% Improvement (To PI)
PC 1	84	11	58	81	87
PC 2	39	15	289	95	62
PC 3	42	20	76	74	52
PC 4	50	18	142	87	64
TC 1	11	0,4	3,9	90	96
TC 2	249	27	31	13	89

4. Conclussions

1. Controlling the pressure and the temperature steam reformer compressor using the MPC has better results than the PI controller. MPC shows that it can optimize the system, unlike the case with PI controller that takes a long time to optimize the system.
2. Empirical models used to perform tuning PI on previous studies have not produced an optimum performance when used in the MPC.
3. MPC parameter modification cannot be done with non-adaptive tuning strategy, so it must be done by fine tuning strategies.
4. System Re-identification and fine tuning of MPC is able to improve the performance of pressure control of compressor and temperature in steam reformer, resulting in a better performance by % improvement of 73% against MPCWSRI and 75% against the PI controller.
5. MPC controller successfully improves the performance of the pressure control to the compressor 1 as much as 7.4 times better, compressor 2 as much as 2.6 times better, compressor 3 2 times better, Compressor 4 as much as 2.7 times better, the heater temperature steam reformers as much as 27 times better, and the column temperature on the combustor steam reformer as much as 9 times better.

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