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Design Of A Model Predictive Control For A Multivariable Process

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Abstract:

Model Predictive Control is a process control technique that is used in process industries that predict the future behavior of the process state by predicting the change in the dependent variables of the modeled system. It can compute the future input at each step by minimizing a cost function on the manipulated and controlled variables. The main goal of this paper is to design a Model Predictive for a multivariable process. Here, the distillation column is used as a multivariable process. Finally, the settling time, overshoot, ISE, IAE, ITAE errors of MPC controller is compared with PID controller for both SISO and MIMO systems.

Keywords: Model Predictive Control, distillation column.

1. Introduction:

The most commonly used separation method that is used in petroleum and chemical industries for purification of final products is distillation. It is not only used for the purpose of separation but also for transferring heat energy and enhancing mass transfer. The control structure is based on Liquid-Vapor structure or the energy balance method. Here, the control inputs are the vapor flow rate and the liquid flow rate. The objective is to maintain the specification of the product concentration outputs. The Model Predictive Control has been selected for controlling the distillation column. The basic concept involved is to predict the future response with the help of a process model and to minimize a finite horizon objective which consists of future predicted errors and control moves.

This paper represents the details about the simulated case of MPC. The Wood and Berry 2x2 transfer function has been taken as the primary system which separates methanol and water. The system outputs are the distillate and bottom compositions which are controlled by the reflux and steam flow rates.

A simple first order transfer function of MPC is compared with PID controller for SISO process. Similarly, the MPC controller is being compared with PID for MIMO (2x2 Wood and Berry) process. Finally, the settling time, peak overshoot and the errors like ISE, IAE and ITAE are compared for MPC and PID controller. The simulation is done by using MATLAB and Model Predictive Control Toolbox.

2. Distillation Column

2.1 Process Description:

The most commonly used process that separates two or more components into distillate and bottom is distillation. The bottom product is liquid, while the distillate may be liquid or vapour or both. The main parts of distillation column are vertical column, trays, reboiler, condenser and reflux drum. The trays are used to enhance the component separation. A reboiler is used to provide heat for vaporization from the bottom of the column and condenser, to cool and condensate the vapour from the top of the column. A reflux drum is used to hold the condensed vapour, so that the liquid can be recycled back from the top of the column.

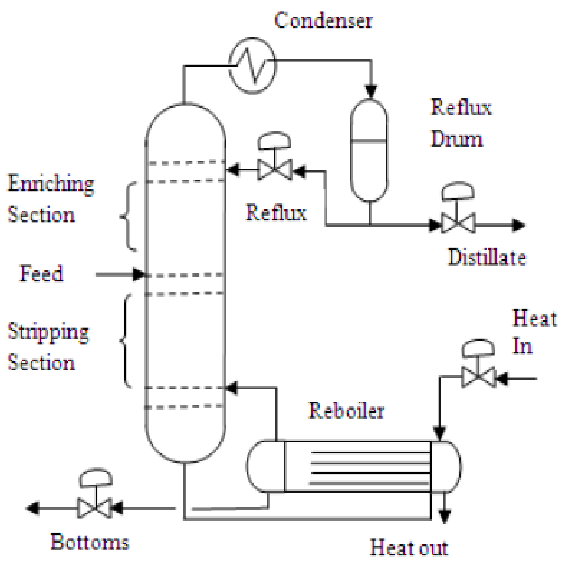

Figure 1: Schematic Diagram of Distillation Column

The distillation column consists of one feed streams and two product streams. The product stream at the top has a composition. The product stream leaving the bottom contains a composition. The column has two sections namely top section and bottom section. The top section is known as rectifying section while the bottom section is known as stripping section.

3. Model Predictive Control

3.1 Basic Concept

The current values of the output variables is used to predict the process model. The residuals i.e., the error is the sum of process outputs and the difference between the model outputs. Set point is generally called as target. Set point calculations and control calculations are the two types of predictions used in MPC calculations. Similar to both internal model control and smith prediction control is the MPC configuration in which the model acts with the process in a parallel manner and the residue serves as a feedback.

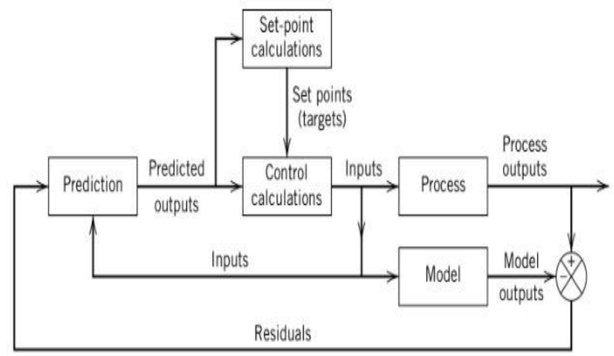

Figure 2: Block Diagram of MPC

MPC has a much greater impact on industrial practice than other controllers because it is more suitable for MIMO control problems. MPC has many salient features such as static and dynamic behavior of input and output variables.

3.2 Principle of MPC

The calculations of MPC are based upon the current measurement and the future values of the output. To determine the sequence of control moves, the predicted response moves to the set-point in an optimal manner is the main objective of MPC calculations.

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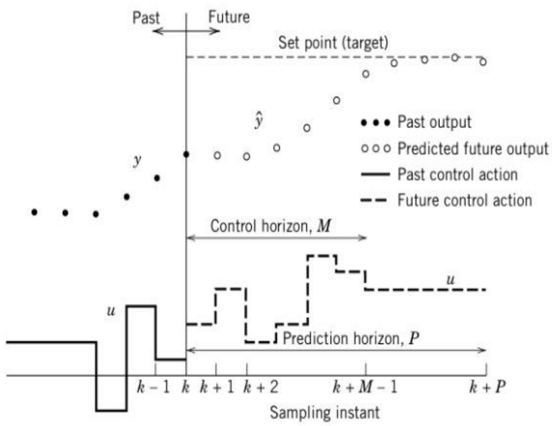

Figure 3: Principle of MPC

In the above figure, the actual output, predicted output and manipulated input are shown. The MPC strategy calculates a set of M value inputs at the current sampling instant. The set consists of current inputs and future inputs. After M control moves, the input is held constant. The inputs are calculated so that the predicted output reaches the set-point. Prediction horizon is the number of predictions while the control horizon is the number of control moves.

4. Simulation Results and Discussion

4.1 SISO Systems:

A simple SISO system is taken for study.

$$\frac{Y(S)}{X(S)} = \frac{1}{10s+1} e^{-0.2s}$$

PID and MPC controller are designed for the above process. The set point tracking with minimal overshoot is achieved using the tuning strategy. The Model Predictive Control is simulated by using MATLAB and Model Predictive Control Toolbox. The output response of the controllers are given below:

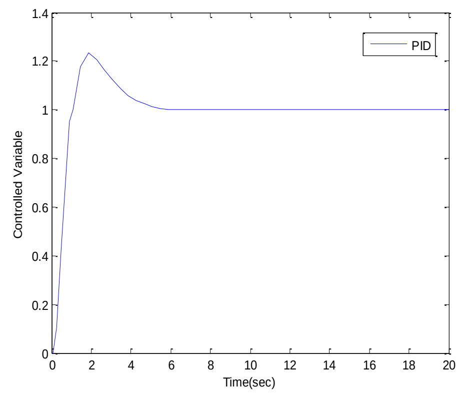

Figure 4: Response of PID Controller

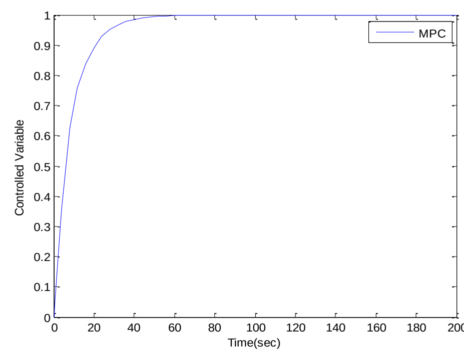

Figure 5: Response of MPC

Table 1: Performance of PID and MPC controller of SISO System

Parameter	PID Controller	MPC Controller
Settling time	6	4.8
Overshoot	1.24	1.04
ISE	2.338	1.776
IAE	5.898	4.748
ITAE	2.926	1.237e+005

4.2 MIMO System

A typical Wood & Berry Binary Distillation column has been taken as the primary system:

$$G(s) = \begin{bmatrix} \frac{12.8e^{-s}}{16.7s} & \frac{-18.9e^{-3s}}{21s+1} \\ \frac{6.6e^{-7s}}{10.9s+1} & \frac{-19.4e^{-3s}}{14.4s+1} \end{bmatrix}$$

The output response of the controller are as follows:

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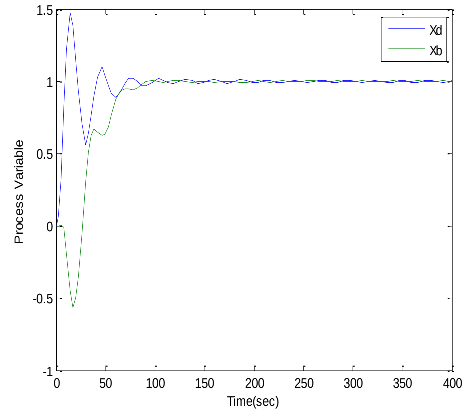

Figure 6: Response of MIMO PID

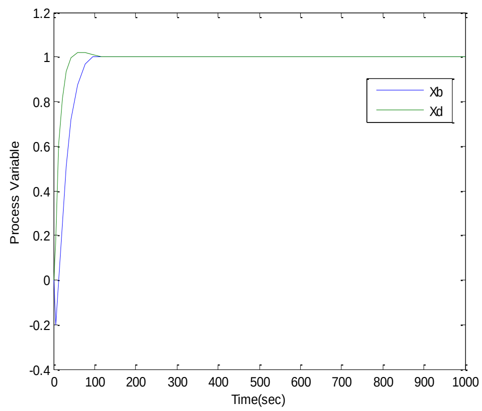

Figure 7: Response of MIMO MPC

Table 2: Performance of PID and MPC controller of MIMO System for top product (X_d)

Parameter	PID Controller	MPC Controller
Settling time	93	59.18
Overshoot	1.48	0.015
ISE	4.793	1.879
IAE	5.81	3.046
ITAE	40.35	18.96

Table 3: Performance of PID and MPC controller of MIMO System for top product (X_b)

Parameter	PID Controller	MPC Controller
Settling time	110	78.64
Overshoot	-0.65	1.2
ISE	28.13	4.68
IAE	20.74	8.598
ITAE	248.81	94.84

5. Particle Swarm Optimization (PSO) Algorithm

One of the most commonly used heuristic algorithm for solving complex optimization problems is Particle Swarm Optimization. It consists of cognitive search and global search.

5.1 Performance Analysis

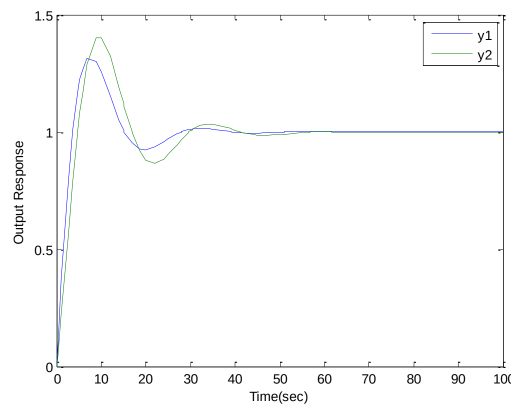

Figure 8: Response of PSO using PI

Table 4: Response of PSO using PI

Parameter	PSO based PI	
Loops	Loop 1	Loop 2
Settling time	29.5	29.5
Overshoot	1.293	1.4
ISE	1.248	2.486
IAE	4.084	6.154

5. Conclusion

The primary system model that is taken here is Wood and Berry distillation column. The 2 input 2 output system is controlled with PID and MPC controller. The performance indices like settling time, overshoot and errors like ISE, IAE and ITAE are compared with different controllers. It is seen that, MPC is far better than all other controllers. Therefore, MPC is much suitable for industrial applications.

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