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Internal Model Control of Distillation Column With Optimal Pairing Technique

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ABSTRACT : The RGA provides a quantitative approach to the analysis of the interactions between the controls and the output, and thus provides a technique for pairing manipulated and controlled variables to generate a control scheme. In this paper, bottom concentration and distillate concentration of (2x2) distillation column is maintained at desired level in methanol and water separation process. Relative gain Array is applied to convert the MIMO system into multiple SISO system. Based on the results obtained from the RGA, Internal Model Controller is designed for the best pairs of manipulated and controlled variable in the separation process in the distillation column. Thus the desired concentration of the bottom and distillate (top) in the distillation column is maintained.

KEYWORDS: Internal Model Controller, Relative gain array, Niederlinski index

I. INTRODUCTION

In SISO system, it consists of only one manipulated variable and one controlled variable. It is clear that, only one variable affect the output of the system. Design a controller in SISO system is simple and accurate.

Control of multivariable systems requires more complex analysis then that of single variable system. Fortunately, essentially all methods and results learned for single variable systems are applicable to multivariable systems. Thus, aspects of a single variable system that make it easy or difficult to control have generally the same effects for multivariable systems. However, in multivariable systems new characteristics due to interaction must be considered. Interaction results from process relationship that causes a manipulated variable to affect more than one controlled variable.

This is the major difference from single loop systems and has a profound effect on the steady state and dynamics behavior of a multivariable system. Thus, it is not possible to analyze each manipulated – controlled variable connection individually to determine its performance; the integrated control system must be considered simultaneously.

A closely related new issue is the disturbance source, because multivariable responds differently to different disturbances. For example, the chemical reactor responds differently to disturbances in feed composition and feed temperature, and, as we shall see, these differences must be considered in designing a multivariable control system. Another realistic issue is the number of controlled and manipulated variable, which may not be equal. In some of the cases, four manipulated variables, this can be adjusted to control three measured variables.

There are two basic multivariable control approaches. The first is a straight forward extension of single-loop control to many controlled variables in a process and this is termed multi-loop control has been applied with success for many decades. The second main category is centralized control in which a calculated algorithm uses all measurements to calculate all manipulated variables simultaneously. The multi-loop approach, using multiple single loop controllers, was the first approach used for multivariable control in the process industries.

block diagram

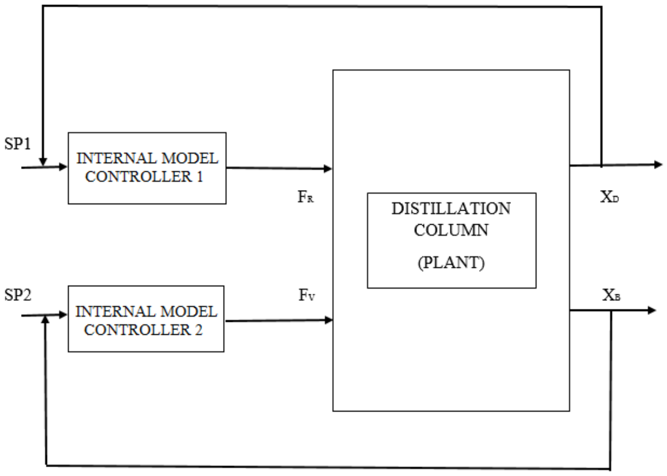

Figure1. Block diagram

In MIMO system, process interaction is an important factor influencing the behaviour of the multivariable systems. A quantitative measure of interaction is needed to proceed with multiloop analysis method, and the relative gain array, which has proved useful in control system analysis, is introduced to meet this need.

The relative gain array is matrix composed of elements defined as ratios of open-loop to closed-loop gains. In this distillation process, the manipulated variables are reflux and reboiler flow rates, and the controlled variables are distillate and bottom composition. Other important variables, such as pressure and levels, are controlled tightly.
In this process, to find the best pair of manipulated and controlled variables. Relative gain array technique is employed, after some computation works RGA gives results in which best pair of the manipulated and controlled variables are found. Reflux flow rate and top distillate composition is the first best pair and reboiler flow rate and bottom composition is the second best pair found from the results of relative gain array.

Thus, Internal model controller for each pair (i.e.) refluxes flow - distillate composition and reboiler flow – bottom compositions are designed to control the composition of distillate and bottom of the distillation tower. Plant model is derived from the fundamental rules and by various techniques Thus, two controller designed to each best pair obtained from RGA and each controller tuned to control the process output.

MATLAB tool is used to simulate the methanol-water separation process in the distillation column. Plant model and Internal model controller was connected in required fashion to simulate the process.

II. DISTILLATION COLUMN

The liquid mixture that is to be processed is known as the feed and this is introduced usually somewhere near the middle of the column to a tray known as the feed tray. The feed flows down the column where it is collected at the bottom in the reboiler.

Heat is supplied to the reboiler to generate vapour. The source of heat input can be any suitable fluid, although in most chemical plants this is normally steam. In refineries, the heating source may be the output streams of other columns. The vapour raised in the reboiler is re-introduced into the unit at the bottom of the column. The liquid removed from the reboiler is known as the bottoms product or simply, bottoms.

The vapour moves up the column, and as it exits the top of the unit, it is cooled by a condenser. The condensed liquid is stored in a holding vessel known as the reflux drum. Some of this liquid is recycled back to the top of the column and this is called the reflux. The condensed liquid that is removed from the system is known as the distillate or top product. Thus, there are internal flows of vapour and liquid within the column as well as external flows of feeds and product streams, into and out of the column.

A schematic of a typical distillation unit with a single feed and two product streams figure 2 is shown below:

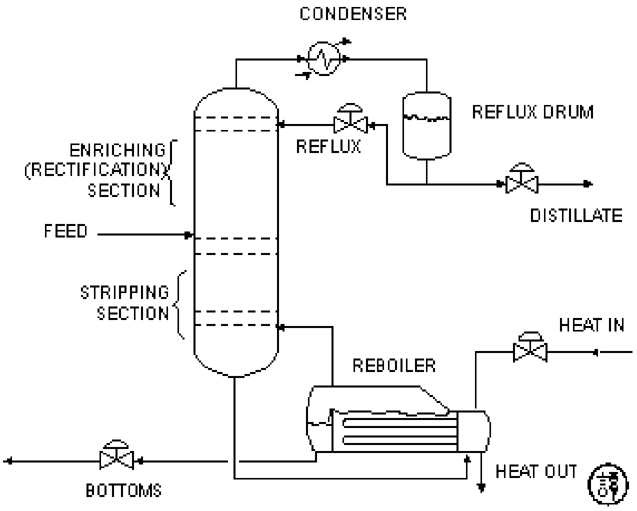

Figure2. Distillation column

The plant model of (2x2) distillation column is given below,

$$\begin{bmatrix} X_D(s) \\ X_B(s) \end{bmatrix} = \begin{bmatrix} \dfrac{0.0747e^{-3s}}{12s+1} & \dfrac{-0.0667e^{-2s}}{15s+1} \\ \dfrac{0.1173e^{-3.3s}}{11.7s+1} & \dfrac{-0.1253e^{-2s}}{10.2s+1} \end{bmatrix} \begin{bmatrix} F_R(s) \\ F_V(s) \end{bmatrix} + \begin{bmatrix} \dfrac{0.70e^{-5s}}{14.4s+1} \\ \dfrac{1.3e^{-3s}}{12s+1} \end{bmatrix} X_F(s) \qquad (1)$$

III. RELATIVE GAIN ARRAY

Single variable Input or Single variable Output (SISO) control schemes are just one type of control scheme that engineers in industry use to control their process. They may also use MIMO, which is a Multi-Input-Multi-Output control scheme. In MIMO, one or more manipulated variables can affect the interactions of controlled variables in a specific loop or all other control loops.

A MIMO control scheme is important in systems that have multiple dependencies and multiple interactions between different variables, in a distillation column, where a manipulated variable such as the reflux ratio could directly or indirectly affect the feed flow rate, the product composition, and the reboiler energy.

Thus, understanding the dependence of different manipulated and controlled variables in a MIMO control scheme could be extremely helpful in designing and implementing a control scheme for a process. One method for designing and analyzing a MIMO control scheme for a process in steady state is with a Relative Gain Array (RGA). RGA is useful for MIMO systems that can be decoupled.

A good MIMO control scheme for a system that can be decoupled is one that can control a process variable without greatly affecting the other process variables. It must also be stable with respect to dynamic situations, load changes, and random disturbances. The RGA provides a quantitative approach to the analysis of the interactions between the controls and the output, and thus provides a method of pairing manipulated and controlled variables to generate a control scheme.

Relative Gain Array is an analytical tool used to determine the optimal input-output variable pairings for a multi-input-multi-output (MIMO) system. In other words, the RGA is a normalized form of the gain matrix that describes the impact of each control variable on the output, relative to each control variable's impact on other variables.

The process interactions of open-loop and closed-loop control systems are measured for all possible input-output variable pairings. A ratio of this open-loop 'gain' to this closed-loop 'gain' is determined and the results are displayed in a matrix.

$$RGA = \Lambda = \begin{bmatrix} \lambda_{11} & \lambda_{12} & \dots & .\lambda_{1n} \\ \lambda_{21} & \lambda_{22} & \dots & \lambda_{2n} \\ . & & & \\ . & & & \\ \lambda_{n1} & . \; . \; . & . \; . & \lambda_{nn} \end{bmatrix} \tag{2}$$

The array will be a matrix with one column for each input variable and one row for each output variable in the MIMO system. This format allows a process engineer to easily compare the relative gains associated with each input-output variable pair, and ultimately to match the input and output variables that have the biggest effect on each other while also minimizing undesired side effects.

The relative gain array can be evaluated from steady state gain matrix,

$$RGA = \Lambda = \begin{bmatrix} 6.09 & -5.09 \\ -5.09 & 6.09 \end{bmatrix} \tag{3}$$

From the result of relative gain array best pairs of manipulated and controlled variables are found. Since only the pairing XD-FR and XB-FV has a positive relative gain value. Thus, reflux flow – distillate composition and reboiler flow – bottom composition found to be best pairs.

IV. NIEDERLINSKI INDEX

NI, the Niederlinski Index, is a calculation used to analyse the stability of the control loop pairings using the result of the RGA, evaluated at Steady State:

$$NI = \frac{|G|}{\prod_{i=1}^{n} g_{ii}} \tag{4}$$

A negative *NI* value indicates instability in the control loop. For a 2x2 matrix, a positive *NI* value indicates stability in the pairings, but this is not necessarily true for larger matrices! For matrices larger than 2x2, a conclusion can only be drawn from a negative *NI*, which indicates instability.

A negative value for *NI*, when all the control loops are closed, implies the system will be integrally unstable for all possible values of controller parameters. In order to design a decentralized control system for a process, given the transfer function, the RGA is used to obtain a tentative loop pairing, and then the *NI* is used to ascertain the stability of the closed loop system using the recommended RGA pairing.

The Niederlinski index value for steady state gain matrix for the equation (1)

NI=0.1643

Hence, the *NI* value is positive and it indicates that the stability in pairs obtained from RGA. Thus, optimal pairing of control loop is obtained from Relative gain array and Niederlinski index stability analysis of pairing.

V. INTERNAL MODEL CONTROL DESIGN

The main advantage to IMC is that it provides a transparent framework for control-system design and tuning. The IMC design procedure is exactly that of the open loop control design procedure. Remember that a factorization of the process model was performed so that the resulting controller would be stable. If the controller is stable and the process is stable, then the overall controlled system is stable. This is true simply because if two transfer functions are stable, then the transfer functions cascaded together are stable. Although the IMC design procedure is identical to the open loop control design procedure, the implementation of IMC results in feedback system. Thus, IMC is able to compensate for disturbance and model uncertainty, while open-loop control is not. Note that the internal model controller must be detuned to assure stability if there is model uncertainty.

A.IMC Structure

The IMC structure is shown in figure (3). The distinguishing characteristic of this structure is the process model, which is parallel with the actual process (plant).

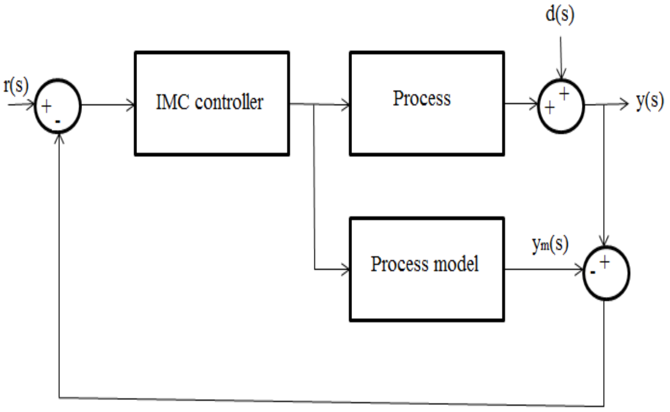

Figure3. The internal model control structure

B.IMC design procedure

The IMC design procedure for SISO system is identical to the design procedure that we developed for open loop controller design earlier. Model uncertainty is handled by adjusting the filter factor for robustness and speed of response.

The IMC design procedure consists of following four steps.

1. Factor the process model into invertible and non- invertible elements.
2. Form the idealized IMC controller. The ideal internal model controller is the inverse of the invertible portion of the process model.
3. Add the filter to make the controller proper.
4. Adjust the filter-tuning parameter to vary the speed of the closed loop system.

Based on above procedure the Internal Model Controller is designed for process used in this paper

For the process 1 the IMC controller is $\dfrac{12s+1}{0.0747s+0.0747}$

For the process 2 the IMC controller is $\frac{10.2s+1}{-0.1253s-0.1253}$

VI. SIMULATION RESULTS

The process is simulated using MATLAB simulink tool and the results of the paper are shown below in figure 3 and figure 4.

Figure 3 gives the result for the control of best pair found from RGA technique, reflux flow and distillate composition.

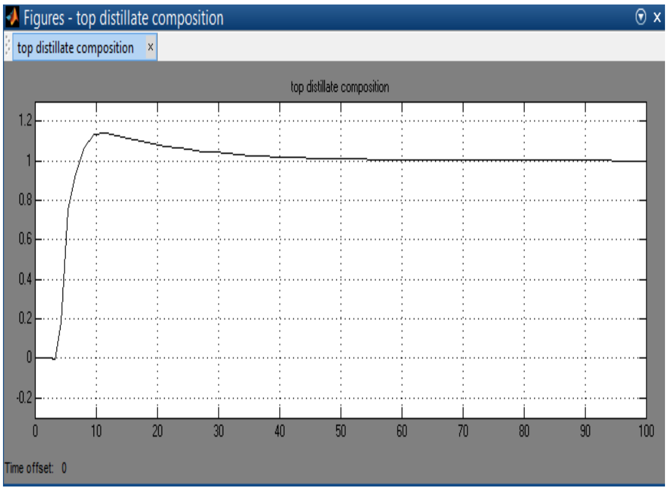

Figure3.Result for the control of top distillation composition
With feed disturbance and interaction of other process

Figure 4 gives the result for the control of best pair found from RGA technique, reboiler flow rate and bottom composition.

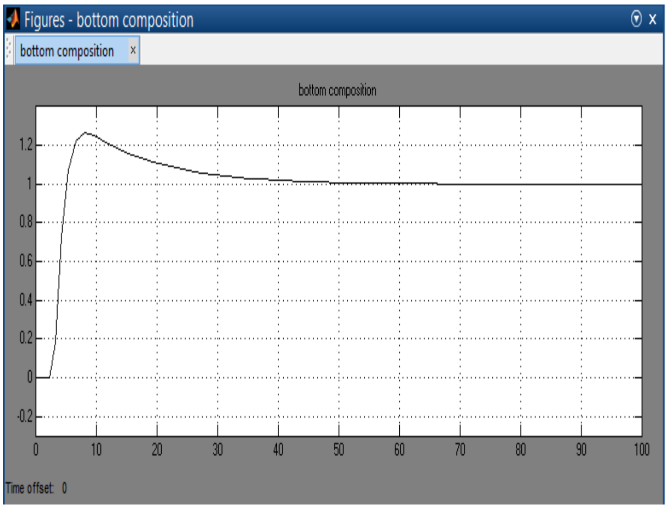

Figure4.Result for the control of bottom composition
With feed diturbance and intreaction of other process

VII. CONCLUSION

The best pairs of distillation column found using Relative gain array technique and Niederlinski index. Internal model controller is designed for the best pair and it is properly tuned. The process is simulated using MATLAB SIMULINK tool and results are obtained. Thus the top and bottom composition of distillation column is controlled and desired performance is achieved.

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